DOT/FAA/TC-10/06

Federal Aviation Administration
William J. Hughes Technical Center
Atlantic City International Airport, NJ 08405

En Route Data Communications: Experimental Human Factors Evaluation

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December 2010

Technical Report

U.S. Department of Transportation
Federal Aviation Administration

NOTICE

Technical Report Documentation Page

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
DOT/FAA/TC-10/06		

4. Title and Subtitle	5. Report Date / 6. Performing Organization Code
En Route Data Communications: Experimental Human Factors Evaluation	**5. Report Date** December 2010 **6. Performing Organization Code** AJP-6110
7. Author(s) Ben Willems, Human Factors Team – Atlantic City, ATO-P Sehchang Hah, Human Factors Team – Atlantic City, ATO-P Kenneth Schulz, Hi-Tec Systems, Inc.	**8. Performing Organization Report No.** DOT/FAA/TC-10/06
9. Performing Organization Name and Address Federal Aviation Administration Human Factors Team – Atlantic City, ATO-P William J. Hughes Technical Center Atlantic City International Airport, NJ 08405	**10. Work Unit No. (TRAIS)** **11. Contract or Grant No.**
12. Sponsoring Agency Name and Address Federal Aviation Administration Human Factors Research and Engineering Group 800 Independence Avenue, S.W. Washington, DC 20591	**13. Type of Report and Period Covered** Technical Report **14. Sponsoring Agency Code** ATO-P

15. Supplementary Notes

16. Abstract

Data Communication (Data Comm) is one of the key enablers required for the implementation of the Next Generation Air Transportation System (NextGen) Plan. NextGen addresses increasing air traffic levels and complexity for 2015 and beyond (Joint Planning and Development Office, 2007). We present the experimental evaluation of Data Comm between en route controllers and pilots as an alternative to voice communication. We conducted the evaluation using an augmented emulation of the En Route Automation Modernization (ERAM) system. In 2009, the Federal Aviation Administration (FAA) has started to replace the current Display System Replacement and Host Computer System with ERAM. We recorded and analyzed system, controller performance, and controller self-report data. We also recorded and analyzed controllers' eye movements and oxygenation levels of the prefrontal cortex using functional near infrared technology. Our results showed that the most useful Data Comm interface was the Human-Machine Interface that combined keyboard, template, and graphical capabilities. An increase in the proportion of the aircraft that were Data Comm capable reduced the frequency of voice communications and lowered controller workload. Data communication failure of individual aircraft did not affect controller performance, but partial or full system failure increased the number of voice communications and workload. For the aircraft that did not have an integrated Flight Management System (FMS), controllers did not opt to use voice communications more often than using Data Comm, but integrated FMS reduced their workload. Our analysis did not find a difference between first-come, first-served and best-equipped, best-served policies. On the basis of these results, we presented recommendations for the NextGen Data Comm.

17. Key Words	18. Distribution Statement
Air Traffic Control Data Communications (Data Comm) Human-in-the-Loop Experiment Human-Machine Interface Next Generation Air Transportation System (NextGen)	This document is available to the public through the National Technical Information Service, Alexandria, VA 22312. A copy is retained for reference at the William J. Hughes Technical Center Library.

19. Security Classification (of this report)	20. Security Classification (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	183	

Form DOT F 1700.7 (8-72) Reproduction of completed page authorized

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Acknowledgments

To prepare and conduct a complex experiment like this one involves many people from diverse backgrounds and organizations. Although we will call out many of the people involved in this experiment, we are sure that our list of people that made the experiment possible is not complete. When acknowledging the individual contributions, we have used an alphabetical order by last name and have omitted affiliations.

The participating controllers made this experiment possible. The 28 controllers from several Air Traffic Route Control Centers within the Continental United States traveled to our facilities, worked diligently on high-traffic simulation scenarios, answered all our questions, and volunteered to wear equipment to measure eye movements and brain activity.

This experiment focused on data communications to complement traditional voice communications. During these types of experiments, we enlist the help of simulation pilots to respond to controller instructions and maneuver the simulated aircraft in the Target Generation Facility (TGF) software to execute the voice-based clearances. In this experiment our simulation pilots had additional tasks that included using data communications to send requests to the controllers and responding to digital clearances received from controllers over the data communications channel.

Human factors and air traffic support personnel prepared the simulation; collected, reduced, and analyzed data; assisted in writing the final report; and provided comments and feedback. Jim McGhee and Richard Ridgway prepared traffic scenarios. John DiRico, Liesl Powers, and Kelly Stephenson, our subject matter experts, trained controllers on the many new functions introduced in our simulation environment and conducted over-the-shoulder observations. Atul Deshmukh, Kevin Hallman, and Bina Patel used functional near infrared equipment to assess brain activity. Kevin Hallman operated the audio and video recording equipment while managing the simulation software. Mark Hale collected visual scanning data using our eye-tracking equipment. Atul Deshmukh, Kevin Hallman, and Jennifer Ross assisted in data reduction and analysis.

A complex simulation like this is possible only because we have excellent laboratory and computer science support personnel. Albert Macias not only manages the Research Development and Human Factors Laboratory, but he also wrote the software that integrated eye-tracking data with the data collected in our high-fidelity simulation environment. Matt Bruckner, Joel Grochowski, Vince Locasale, Gary Mueller, Chris Parratto, Nicole Smith, Yev Tabekman, and Valentina Velez programmed many of the new features in the Distributed Environment for Simulation, Rapid Engineering, and Experimentation (DESIREE). Dan Johnson, Matt Zeits, and several others from the DESIREE team managed the data we collected and reduced down to a form that we could use in our analyses. Wallace Daczkowski, John Dilks, and Ed little kept all our systems going during the experiment.

The Data Communications Program Office was not only our main customer, but they also provided great support during the experiment. Tom Cleary was present during several of our data collection sessions and exit briefings. Hal Albert, Paul Debenedittis, Steve Ferra, and Jerry Smith have continued to work on data communications and provided feedback and suggestions during the implementation of the simulated data communications services.

This experiment addressed issues relevant to Data Communications Segment 1 and Segment 2. The Air Traffic Services Concept Development and Validation Group took on the enormous task of recruiting participants and coordinating their travel. Kelvin Feik was instrumental in bringing participants to our facilities. Danny Benbassat, Levent Ileri, and Farilee Mintz worked with us in developing the initial concepts and coordinated our briefings and reports.

Our simulated aircraft do not fly without the TGF. Samantha Fullerton, Dana Whicker, and others behind the scenes created data communications capabilities that did not exist in the TGF before we started this experiment. Simulated aircraft for the first time were able to receive many of the Data Communications Segment 1 messages; and simulation pilots were able to receive, monitor, and send these messages. Samantha Fullerton, Rhoma Gordillo, and others ensured smooth operation of the TGF and simulation pilot workstations.

Drexel University was a partner in this experiment. We had set aside one day for a part-task experiment that another publication will cover. During the main experiment, we used equipment developed at Drexel University that assessed brain activity using functional near infrared to measure oxygenation levels. Hasan Ayaz, Scott Bunce, Kurtulus Izzetoglu, and Patricia Shewokis spent many hours with us discussing the data collection, reduction, and analysis of the data we were collecting with their system.

The en route operational services provided subject matter experts during the preparation for the experiment. It also allowed our detail controllers to participate and released 28 controllers to work in our simulations. Taylor Pruitt was instrumental during the coordination with Kelvin Feik to ensure that our participants were present when we needed them.

To all of you called out in the previous paragraphs and those that we did not mention by name, we thank you for your contributions that made the execution of this experiment possible.

Executive Summary

The Next Generation Air Transportation System (NextGen) Plan addresses issues related to increasing air traffic levels and complexity (Joint Planning and Development Office, 2007). NextGen will transform the current surveillance, navigation, and communication systems and greatly alter the role of the pilot and air traffic controller. The Federal Aviation Administration (FAA) is developing new concepts and procedures that align with NextGen goals and include Data Communication (Data Comm) as a major part of the NextGen. In this report, we present the experimental evaluation of Data Comm between the en route controller and pilots as an alternative to strategic Voice Communication (Voice Comm).

We evaluated concepts for creating, editing, sending, receiving, replying to, and monitoring the status of data communication messages. We assessed system and controller performance and efficiency measures at air traffic levels anticipated for 2015 and beyond. We conducted the evaluation using an augmented, simulated En Route Automation Modernization (ERAM) system – which is planned to replace the current Display System Replacement (DSR) starting in 2010.

We recorded and analyzed system and controller performance and self-report data, including the number of aircraft handled, time and distance in the sector, controller workload, situation awareness, and ratings of system features. We also recorded and analyzed controller eye movements and oxygenation levels from the prefrontal cortex using functional infrared technology.

Our results showed that the most useful input mode was the Human-Machine Interface (HMI) that combined keyboard, template, and graphical capabilities. The use of a template as the only input mechanism for data communication messages was less helpful. Increasing levels of data communications equipage reduced voice communications and led to a reduction in workload. The questionnaire data showed that the equipage level did not affect workload in all controller tasks equally. It also indicated that the equipage level did not matter as much to the Data Controller (D)-side as it did to the Radar Controller (R)-side. Data communication failure for individual aircraft did not affect controllers, but partial or full system failure increased the number of voice communications and workload. Although the lack of Flight Management System (FMS) integration did not affect the number of voice communications, it did result in increased controller workload. Our analysis did not find differences between first-come, first-served and best-equipped, best-served policies. The controllers tried to provide preferential service to better equipped aircraft but, instead, suggested that to increase equipage levels, the FAA may need to mandate airlines to equip their aircraft. Based on our results, we provide the following recommendations:

- **General**
    - Use spiral implementation of data communications services.
    - Determine the amount of time it takes before controllers have made Data Comm symbology, procedures, and capabilities part of their routine control behaviors.
    - Determine more realistic pilot response times to different clearance types.
    - Conduct follow-on research that determines acceptable response times for specific message types.
    - Provide visual feedback for the status of voice-based clearances.
    - Provide immediate feedback in the track area when a Data Comm entry fails.

    - Revisit and standardize Data Comm symbology.
    - Provide improved feedback across sector positions.
    - Determine whether the automation can incorporate expected data communications delays in alerts and advisories to advise controllers when to use voice instead of data communications.
- **Human Machine Interface**
    - Provide keyboard and graphical user interface options to controllers to make Data Comm entries.
    - Conduct future studies that address integration of data communications capabilities with new automation functions such as assisted metering maneuvers, conflict resolution advisories, traffic flow initiatives, and weather advisories.
    - Provide more macros than the current ERAM limit.
    - Integrate data communications capabilities in the track area of the situation display when possible.
- **Equipage Levels**
    - Provide adequate training to incorporate data communications in the controller's day-to-day operations.
    - Provide training to teach controllers to recognize situations where the use of data communications is not appropriate, such as tactical situations.
    - Determine the equipage level at which reduction of workload and voice congestion become significant.
- **Best-Equipped, Best-Served**
    - Provide automation support to assist controllers in the implementation of Best-Equipped, Best-Served policies.
- **Flight Management System Integration**
    - Determine more realistic pilot response times that differentiate between integrated and nonintegrated FMS.
    - Conduct air/ground integration studies that include realistic flight deck procedures to establish anticipated pilot response times in domestic airspace.
- **Failures**
    - Provide more immediate feedback about aircraft affected by data communications failures.
    - Conduct follow-on research that investigates how to support controllers during the transition into and from a data communications failure.
- **Round-trip Delay Times**
    - Conduct further research to determine acceptable maximum delay times.
- **Roles and Responsibilities**
    - Establish procedures to formalize intra-team coordination and responsibilities when using data communications services.
    - Provide tools to use the sector displays to support intra-team communications.
    - Conduct human-in-the-loop studies that force controllers to provide all types of advisories required in an operational environment.

1. INTRODUCTION

The Federal Aviation Administration (FAA) projects that the number of flights in the National Airspace System (NAS) will increase by nearly 40% by 2025 (FAA, 2009a). The Joint Planning and Development Office (JPDO) has developed the Next Generation Air Transportation System (NextGen) to address this increase in traffic and complexity (JPDO, 2007a). NextGen is a long-term initiative that spans nearly 20 years and consists of three research and development phases (JPDO, 2007b). Phase 1, which began in 2007 and will continue through 2011, focuses on the development and implementation of the core technologies deemed necessary for enabling new concepts and procedures. These technologies include Data Communications (Data Comm) that use digitally encoded information. During Phase 2, extending from 2012 to 2018, the available core technologies will enable the implementation of new procedures and concepts. Phase 3, extending from 2019 to 2025, will expand the new capabilities throughout the NAS and will phase out older technologies.

As a core technology, Data Comm will enable advanced operations and services to improve safety, capacity, and efficiency. It will support the efficient exchange of trajectory information between air and ground, enabling Trajectory-Based Operations (TBO), including efficient, environmentally beneficial Continuous Descent Arrivals and Tailored Arrival Procedures. Creation of Data Comm messages can be manual, semiautomatic, or automatic. The system can store, retrieve, edit, sort, display, print, and archive messages. For example, once a controller issues a clearance, a pilot can respond to the message with a WILCO (will comply), and the Flight Management System (FMS) can execute that message without re-entering the data, thus eliminating multiple potential sources of errors. The messages persist until the recipient has acknowledged them, eliminating errors due to misidentifying the intended recipient or forgetting. Digital messages require less frequency (or radio) bandwidth and have inherently greater noise immunity than analog voice transmissions.

NextGen will greatly alter the roles of pilots and controllers. The flight crew will become responsible for some procedures, and the controller will become more responsible for airspace management. Replacing some voice communications (Voice Comm) with Data Comm affects visual, auditory, cognitive workload, and attentional demands for aircrew and controllers. Data Comm implementations must take into account human capabilities and limitations as well as integrate well into human tasks and facilitate rapid and accurate human performance. Appropriately, the JPDO (2007b) has identified human factors as a crosscutting research and development area for assessing NextGen initiatives.

We studied several approaches to implementing Data Comm Human-Machine Interfaces (HMIs). We examined the application of Data Comm to support TBO and the implementation of advanced aircraft procedures. We expect that our results will help identify the extent to which Data Comm will increase airspace capacity.

1.1 Background

1.1.1 Previous Research in Data Communications for Air Traffic Control

FAA research into data communications for Air Traffic Control (ATC) dates back to the 1970s (Diehl, 1975; Hilborn, 1975). By the time of Kerns' (1991) review, simulation studies had addressed a wide range of issues, including redundant vs. complementary use of voice and data communications, application areas (noncontrol or tactical or strategic control), procedures, and human-interface design. Kerns suggested to use voice and data as complementary modes of communication, that data communications is useful for all but urgent tactical messages, that controller interfaces should offer a variety of ways to construct messages, and that the system should show message status in close proximity to the aircraft symbol on the controller's display. Areas identified for further research included detailed HMI design and more precise specification of clearances, such as maneuver start and end points and climb or descent rates.

An early study (Data Link Benefits Study Team, 1995) used a segment of historic data from Atlanta Air Route Traffic Control Center (ARTCC) in a human-in-the-loop (HITL) simulation, with the addition of Data Link messaging using the Radio Technical Commission for Aeronautics (RTCA, 1993) message set and 90% equipage. Compared to the original data, Data Comm reduced aircraft transit times for an en route sector and distance flown within the sector by approximately 20%.

Research on the implementation known as Controller-Pilot Data Link Communications (CPDLC) culminated in the introduction of Build 1 at the Miami ARTCC in 2002. Although the agency planned a larger set of messages (Build 1A), the FAA canceled the planned national rollout (Stefani, 2004).

Recent simulation studies at the Research Development and Human Factors Laboratory (RDHFL) have used the Future En Route Work Station (FEWS). The FEWS simulation emulated the En Route Automation Modernization (ERAM) system, with a number of enhanced capabilities, including data communications. These studies have shown that the availability of data communications reduces the number and duration of voice communications and controller workload, resulting in an increase of 20% in sector capacity at equipage levels of 70% (Willems, Hah, Philips, 2008; Willems & Hah, 2008).

1.1.2 Data Communications

The FAA will introduce Data Comm into ATC in several segments. Segment 1 spans years 2012 – 2017 and Segment 2 spans years 2018 – 2023 (approximately). Both Segment 1 and Segment 2 teams participated in developing research questions and message sets for the current simulation experiment. The message set for Data Comm includes the following services: Vertical clearances, crossing constraints, lateral offsets, route modifications, speed changes, and contact/monitor/ surveillance. Pilots may downlink requests for services and reports, and the controller can uplink clearances and requests for reports. Both pilot and controller may send negotiation requests, system management messages, and response or acknowledgment messages (such as WILCO and UNABLE). We presented the complete Segment 1 message set in Appendix A.

The message set includes numerous complex clearances such as clearances that the aircraft will execute in the future at a specified time, at a specified location, or after a completion of a preceding clearance (signified by THEN).

Because of the greatly expanded number of messages (relative to CPDLC Build 1 and Build 1A), and the complexity of messages, we conducted a Cognitive Walkthrough with Subject Matter Experts (SMEs) in July of 2008. The participants provided many comments relating to the use of messages and to requirements for the HMI to construct, send, and receive messages.

On the basis of lessons learned from the CPDLC, EUROCONTROL initiatives, and Cognitive Walkthrough, we developed prototypes of several HMI approaches for demonstration to representatives of various FAA units for review and comment in December 2008.

We created an HMI requirements document for En Route Data Communications (RDHFL, 2008). Design objectives for controller tools and displays include the following:

- Minimize added display clutter and complexity.
- Limit or eliminate the number of disparate windows and lists, or make them optional.
- Provide access to information through the fewest number of steps possible.
- Maintain consistency across display windows.
- Use consistent layout formats to support user learning and automatic human behaviors.

Based on the results of the cognitive walk through and early demonstrations, the Data Comm Program Office requested the execution of an en route Data Comm HITL in 2009 (Data Comm Program Office, 2009).

1.1.3 Extensions to Simulation of ERAM System

We incorporated a simulated version of the proposed ERAM system in our study to evaluate Data Comm concepts. The first version of ERAM was deployed in the field in 2010.

The Segment 1 message set includes clearances that ERAM does not currently record and process. For example, controllers cannot enter commands that are conditional on completion of a cleared maneuver. Therefore, we extended the ERAM simulation with the capability to enter and uplink these complex clearances.

Controllers will use data communications with voice communications because operators will not retrofit all existing aircraft with data communications equipment. Also, some new aircraft will not include data communications equipment for various reasons, especially for financial reasons. Even for Data Comm equipped aircraft, controllers and pilots will communicate verbally for tactical ATC messages due to time constraints. Therefore, the Data Comm design must accommodate both voice and data communications.

1.1.4 Incentives for Early Adopters

The FAA suggests providing incentives for aircraft operators that adopt NextGen technology early. One such incentive is to provide preferential treatment. The NextGen Implementation Plan (FAA, 2009b) suggests moving from a first-come, first-served (FCFS) environment to a best-equipped, best-served (BEBS) priority for operators that adopt NextGen avionics early. The air traffic controller union has expressed concern that this shift in service orientation may affect sector complexity, safety, and controller workload (Forrey, 2009).

1.2 Purpose

We evaluated Data Comm HMI requirements (RDHFL, 2008) in our simulation and compared various alternative HMI approaches: Input modes of keyboard, template, and graphical interaction. We also compared the effects of HMI design on controller performance and workload.

We assessed the benefits and feasibility of the use of Data Comm in the en route environment in terms of system safety, efficiency, and capacity in addition to controller performance, communication behavior, and workload. We compared several levels of Data Comm equipage, FMS integration, and Failure modes.

2. METHOD

2.1 Participants

Our experimental design required 24 participants; 12 teams, 2 controllers for each team: Radar (R) and Data (D) controller. However, we had a computer problem when we had the first group (two teams of two controllers each; a total of 4 controllers). This led us to recruit 28 participants total; all of them were Certified Professional Controller (CPCs) from en route facilities. The participants had medical certificates that were current within 30 days prior to their participation in the experiment. This increased our ability to recruit them while still requiring currency on controlling traffic within the last 60 days. We asked participants, prior to their participation, if they wore bifocals, trifocals, or hard contact lenses. This constraint was due to the design limitations of the oculometer that we used to obtain visual scanning data.

The average age of participants was 44, and the age range was between 24 and 55 years. They had worked as controllers for 20 years on average, which ranged between 3 and 30 years.

2.2 Research Personnel

Two engineering psychologists administered the experiment including briefings, experimental procedure, data collection, and simulator preparation and operation. Two other engineering psychologists prepared the experimental materials and assisted in operating the Distributed Environment for Simulation, Rapid Engineering, Experimentation (DESIREE) system, and the eye movement tracking systems. Two Human Factors Engineers were responsible for operating and collecting Functional Near Infrared (fNIR) data (see section 2.4.5 for a more detailed description about fNIR).

The three SMEs had more than 7 years of experience in the en route centers as CPCs. These SMEs participated in the development of the training and test scenarios. They trained participants on airspace, sector configurations, scenarios, and simulator, including Data Comm features the participants had never experienced before. They also provided Over-the-Shoulder (OTS) ratings of participant performance during experimental runs. Two of them were supervisors at ARTCCs and detailing at our laboratory. One of them was a contractor who had previously worked as a CPC at ARTCCs. Hardware and software engineers prepared all equipment including the displays and the communications system. They were always on standby to assist during the simulation, if needed. Six simulation pilots participated in the simulation; three of them per team.

2.3 Facilities

We conducted this simulation at the RDHFL, which is located at the William J. Hughes Technical Center (WJHTC), Atlantic City International Airport, NJ. Controllers worked in a room that had simulated CPC workstations and associated equipment (see Figure 1). Pilots worked at workstations in a separate room. We recorded participants' communications and actions during the simulation.

Figure 1. Simulation controller room.

2.4 Software and Equipment

In the following section, we describe software, controller workstations, and other equipment used in the experiment.

2.4.1 Software

We used the DESIREE ATC simulator and the Target Generation Facility (TGF) to present the air traffic scenarios. Software engineers at the FAA WJHTC developed both of these systems. The TGF uses preset flight plans to generate radar track information and simulation pilot displays. The TGF also provided an interface that allowed the simulation pilots to maneuver the aircraft. The TGF algorithms controlled aircraft maneuvers to represent realistic aircraft climb, descent, and turn rates. We also used the TGF to record information about aircraft trajectories, aircraft proximity, and other relevant data for subsequent analyses.

DESIREE simulated en route and terminal functionality, allowing researchers to modify or add information and capabilities to the ATC workstations to evaluate the new concept and procedure evaluation. DESIREE received input from TGF and displayed aircraft information on the controller displays, including radar tracks, data blocks, and sector maps. It also allowed controllers to perform the functions they needed in an operational environment. Like TGF, DESIREE had data collection capabilities and stored information of controllers' interaction with it such as controller input entries during an experimental run.

2.4.2 Controller Workstations

The R-side controller workstations had a high-resolution (2,048 x 2,048), 29" radarscope, keyboard, Voice Switching and Control System (VSCS) panel, Keypad Selection Device (KSD), and mouse. The DESIREE system simulated ERAM but had additional control and display elements for Data Communications (see Figure 2 and Figure 3 for examples). In this experiment we have assumed that by 2015, the conflict probe functions will become an integral part of the R-side display. The conflict probe continuously will check current flight plan trajectories for strategic conflicts. The Traffic Management Advisor (TMA) will also compute the sequences and Scheduled Times of Arrival (STAs) to the outer meter arc, meter fix, final approach fix, and runway threshold for each aircraft to meet sequencing and scheduling constraints. We simulated these functions and systems in our experiment.

Instead of the Graphic Plan Display that is available on the D-side display in the field, we provided a radar display identical to the R-side, including the format of data blocks. The D-side retained the tabular format of the Aircraft List. The keyboard and KSD were the same equipment used in the field. They used the off-the-shelf mouse as the slewing and pointing device instead of the trackball that they used in the field.

Figure 2. Data Comm message template.

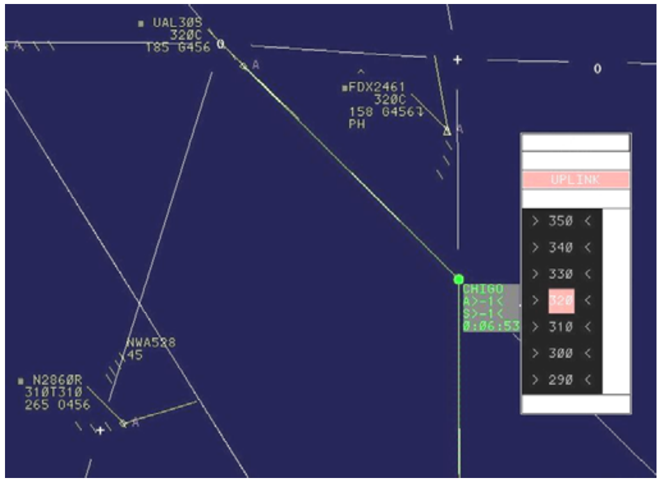


Figure 3. Data Comm Fly Out menu for crossing restriction message.

We used various symbols to signify different states of aircraft Data Comm (see Table 1 and Figure 4 for examples). The symbols appeared to the left of the call sign in the data block. Figure 5 shows various states of Data Comm represented in the data block. Figure 6 through Figure 8 illustrate screenshots of the controller display for the three different failure conditions used in the experiment.

Table 1. Some Schematic Drawings of Data-Communication Status Symbols

Symbol	Description
	On frequency
	Not on frequency
	Open session or session not established
	Transmission in process
	Message failed/timed out (flashing)
	Incoming pilot request

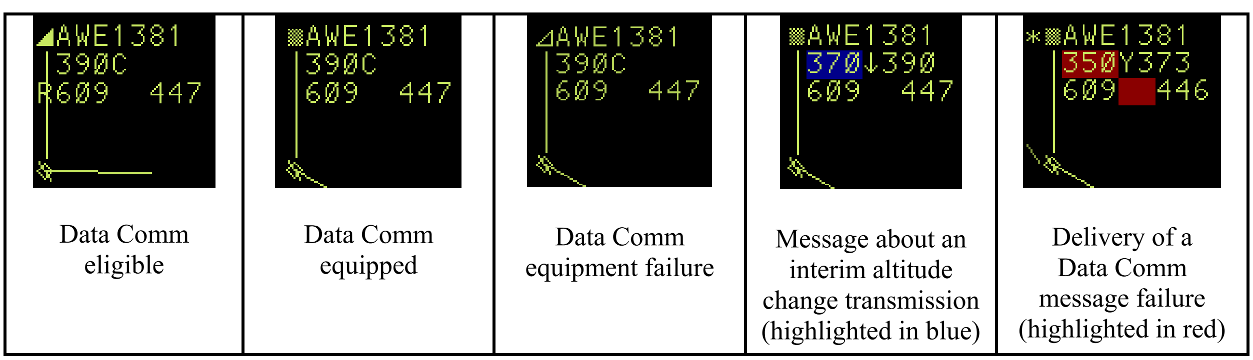


Figure 4. A few examples of data blocks with Data Comm symbols in the normal situation and the failed situation.

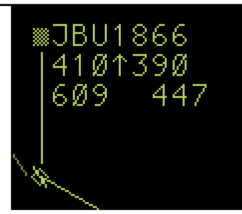
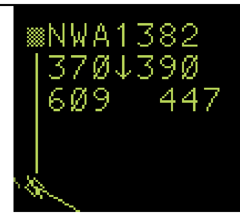
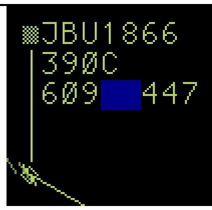
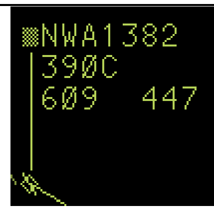
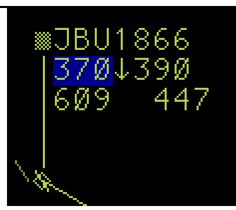
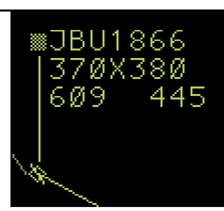
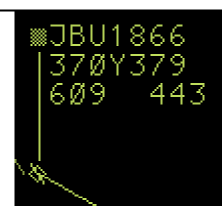
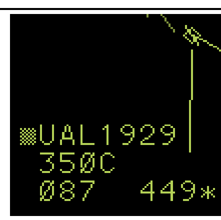
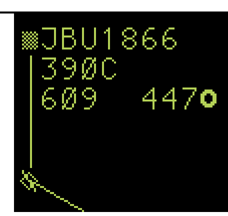
DC messages in progress	Altitude Status indicators	
 DC portal DC message in progress	 Climbing (↑) status	 Descending (↑) status
 Route field message in progress	 Level flight (C) status	 Below assigned altitude (-) status
 Altitude field message in progress	 Above assigned altitude (+) status	 Temporary assigned altitude (T) status
 Speed field message in progress	 Fix-based (X) future clearance status (Data Comm)	 Time-based (Y) future clearance status (Data Comm)
 Heading field message in progress	 Future clearance (*) symbol	 Future clearance (**o**) symbol

Figure 5. Examples of Data Comm symbols showing altitude status and messages transmitted.

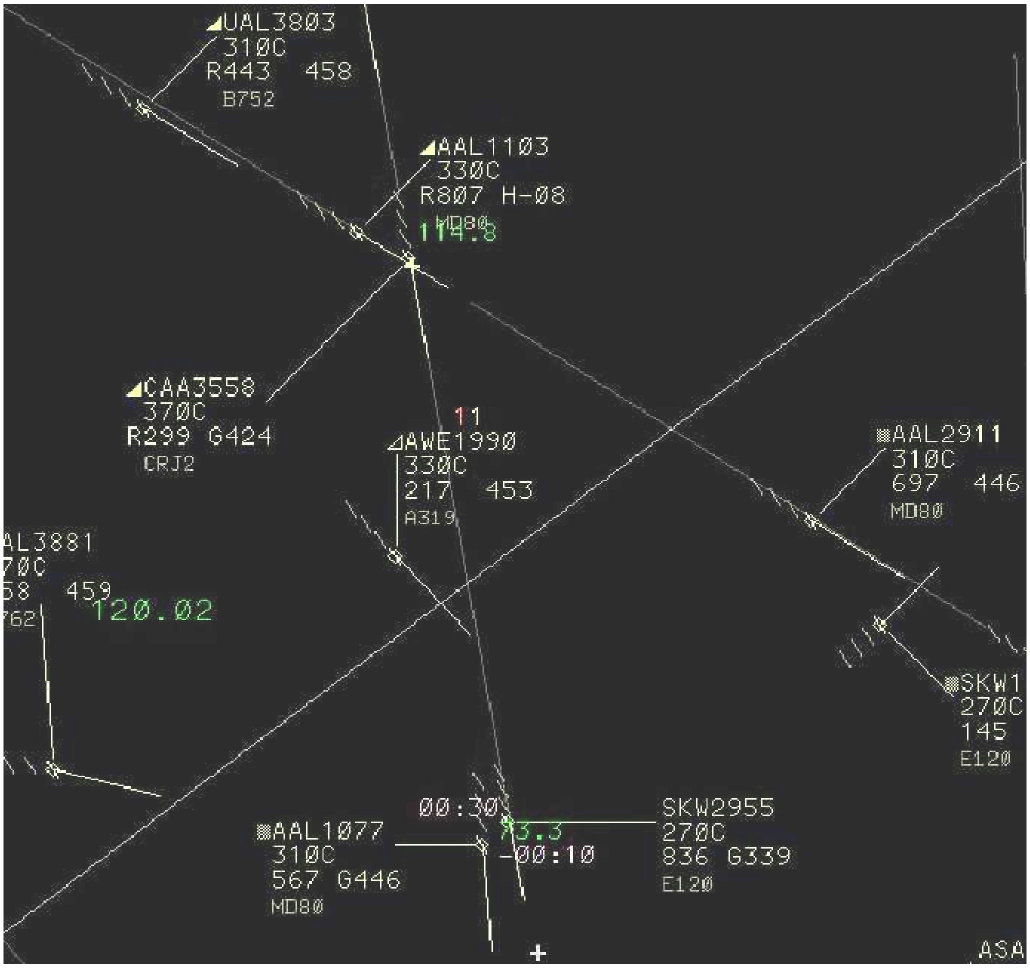


Figure 6. A screen shot showing an individual aircraft Data Comm failure of flight AWE1990.

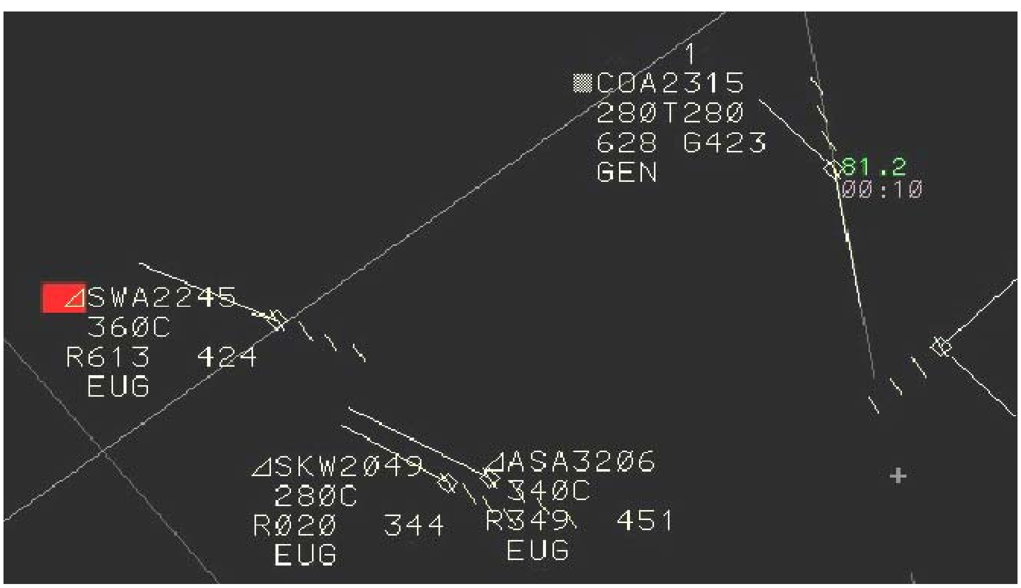


Figure 7. A screen shot of partial failure.

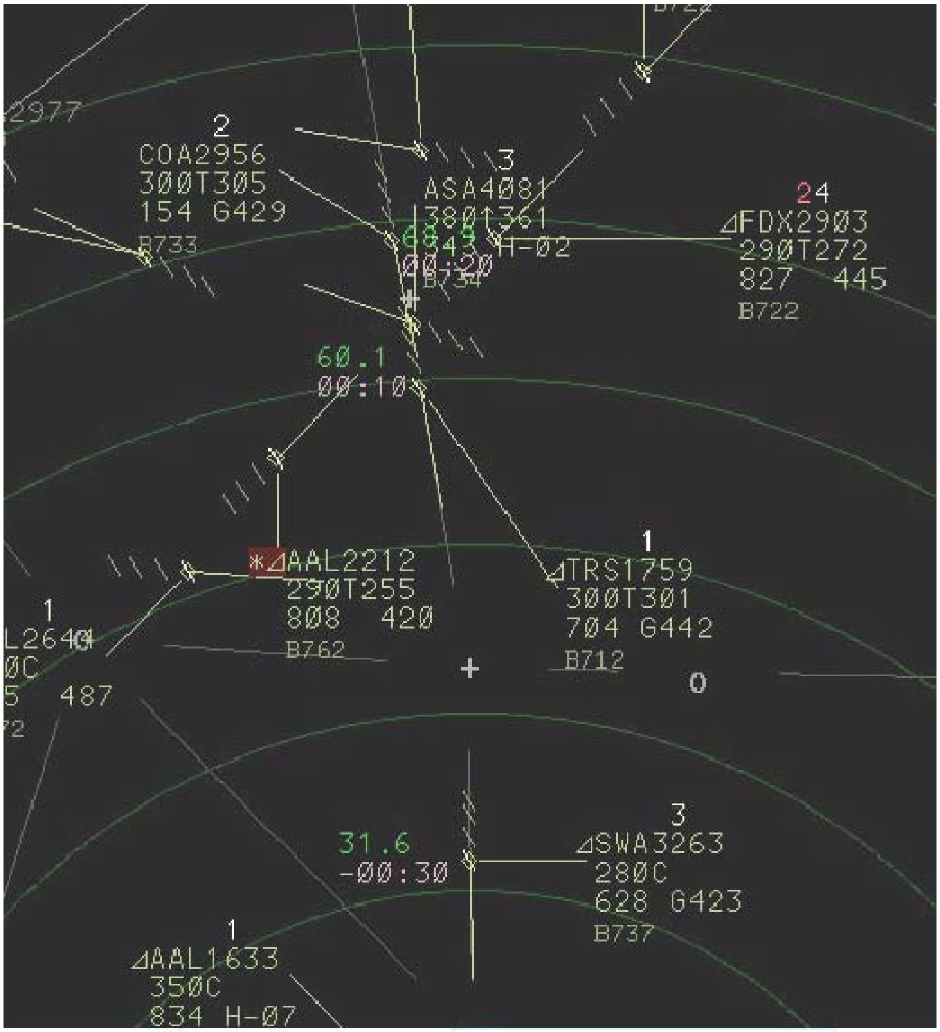


Figure 8. A screen shot of total system failure.

2.4.3 Workload Assessment Keypad

We used a Workload Assessment Keypad (WAK) device (Stein, 1985) to collect workload ratings. We located it at each participant's workstation between the keyboard and the display. The WAK had a panel display with 10 numbered buttons (see Figure 9). It prompted participants to rate their workload, by emitting a single beep and illuminating the keypad buttons every 2 minutes during the 50-minute experimental run. The lighted buttons stayed on for 20 seconds unless the participant pressed a button. If the participants did not respond in 20 seconds, the WAK recorded a missing data code. We instructed the participants to indicate their instantaneous workload level by pressing one of the numbered buttons (see Appendix G). We instructed them to press a button from 1 to 10 rating values. Higher numbers represent higher workloads. At the low end of the scale (1 or 2), workload is low; participants will accomplish tasks easily. Numbers 3, 4, and 5 represent the increasing levels of moderate workload; the chance of error is still low but steadily increasing. Numbers 6, 7, and 8 reflect relatively high workload; there is some chance of making errors. At the high end of the scale are Numbers 9 and 10, which represent a very high workload; it is likely that participants will need to leave some tasks unfinished.

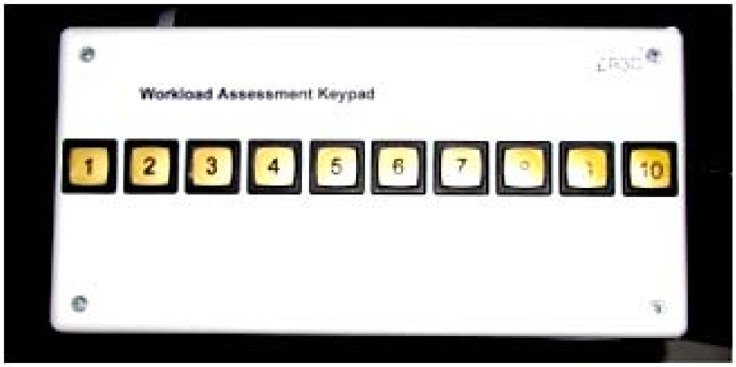


Figure 9. Workload Assessment Keypad.

2.4.4 Oculometer

The oculometer consists of an eye and head tracking system that recorded Point of Gaze (POG) and pupil diameter by using near-infrared reflection outlines of the pupil and the cornea (Applied Science Laboratories, 2007).

Participants wore an Applied Science Laboratories Model 6000 oculometer (Applied Science Laboratories, 2007) consisting of a head mounted eye and head tracking system (see Figure 10). It recorded the eye movements of both R- and D-side controllers in one team. It measured both eye and head movement at 240 Hz to record POGs in x, y (horizontal), and z (vertical) coordinates relative to the scene plane. Its accuracy was .5 degrees.

Figure 10. The picture shows eye movement tracking and fNIR patch partly hidden under the eye movement tracking system.

The system consists of a headband with a camera, an optics system, a visor, a scene camera assembly, a camera control unit, an eye-tracking system control unit, an eye-tracker interface PC, and EYEPOS software. To compensate for head movement, we used a magnetic tracker (The Bird, Ascension Technologies Corporation). The system records POG and pupil diameter, on up to 20 surfaces of interest (such as scene planes, monitor screens, keyboards, walls, etc.) of a person by using near infrared reflection outlines of the pupil and cornea. The oculometer records eye movement of R- and D-side controllers with respect to defined fixed scene planes and provides visual scanning data including information about eye movement pauses or fixations, eye jumps or saccades, blinks, and pupil diameter.

Prior to the experiment, to ensure accurate calculation of the location of the POG, we defined the physical location of all visual areas of interest, also known as scene planes. We defined the exact three-dimensional location of key scene planes relative to the oculometer coordinate system, by creating virtual rectangular boundaries for each scene plane of interest by entering distances of known points and determining the coordinates of each of these points relative to the oculometer. The oculometer then uses the defined position and orientation of the scene planes to determine the local coordinates, which allow the system to determine which scene plane is being viewed and the distance of the eye from the spot being fixed. The oculometer EYEPOS software stores the exact position of the scene planes for use during the experiment.

Prior to each simulation run, we did a participant calibration to correct for the way the head-mounted magnetic head tracker and optical-eye tracker fit on the participant's head, for distortions in the optical system, and for participant seated height differences. To calibrate, we used a 17-point calibration grid displayed on a 2,000 x 2,000 display (see Figure 11). During this participant calibration, we instructed the participant to sit still and to focus his or her gaze on the numbered points as we called them out. We used the oculometer software to automatically enter the participant's POG for each of the 17 points. The software then uses the known locations of these points to determine the adjustments it needs to make to fit POG to the exact location of the calibration points. At the end of the calibration procedure, the experimenter verified that the participant's POG coincided with the system's coordinates by having the participant focus on several points of the calibration grid. If the focused locations correspond to the calibrated location, the experiment continued. If there was a discrepancy, we repeated the participant's calibration procedure.

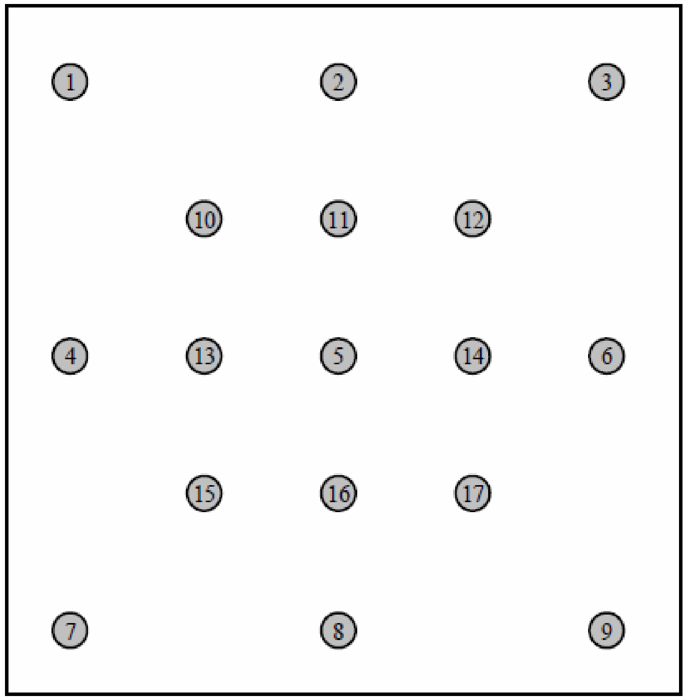


Figure 11. Example of the participant oculometer calibration screen.

2.4.5 Functional Near Infrared

We used fNIR equipment to collect physiological data of controllers' workload. This equipment was portable as well as safe and easy to attach to a person's forehead, and collect data in real time (see Figure 12). It enabled us to monitor the controllers' brain activities while controlling air traffic because it did not hinder controllers' movements. It measured changes of oxygen consumption levels in the dorsolateral and inferior frontal cortex associated with neural activity.

Figure 12. Functional Near Infrared patch.

Neural activity requires oxygen to metabolize glucose for energy, so increases in neural activity result in increases in the utilization of oxygen from regional capillary beds. The oxygen is delivered to the neurons by hemoglobin molecules on red blood cells. As hemoglobin molecules deliver the oxygen to the neural tissue in the capillary beds and take on carbon dioxide, it is transformed into deoxygenated hemoglobin and changes color. Although most biological tissues are relatively transparent to light in the red and near-infrared range of the electromagnetic spectrum between 700 nm and 1,000 nm, hemoglobin is a strong absorber of light in this range.

Photons at these wavelengths tend to pass through most tissues, losing about one decade of intensity for each centimeter traveled, but hemoglobin absorbs them. By choosing one wavelength that is more sensitive to oxygenated hemoglobin and another wavelength that is more sensitive to deoxygenated hemoglobin, the system can calculate changes in their relative concentrations.

The participants wore the fNIR sensor array on their foreheads with a headband. The patch had a silicon pad containing four small Light Emitting Diodes (LEDs) in the middle and 10 light detectors (or sensors) surrounding the LEDs (as shown in Figure 12). From this arrangement, we collected data from 16 different places called voxels inside of the participants' foreheads. Low power light from the diodes shone through the skin of the forehead onto the brain during the experimental run, and sensors recorded the changes of the light that returned.

With this technology, researchers at Drexel University demonstrated the relationship between brain activities and cognitive workload during a naval warship command and control task with other tasks (Bunce, Izzetoglu, Izzetoglu, Onaral, & Pourrezaei, 2006; Izzetoglu, Bunce, Onaral, Pourrezaei, & Chance, 2004; Izzetoglu, Bunce, Izzetoglu, Onaral, & Pourrezaei, 2007).

2.4.6 Voice Communications System

The voice communication system provided a link between the participant and simulation pilots through a Push-to-Talk (PTT) buttons. The system monitored and recorded the times and durations of PTT activities.

2.4.7 Simulation Pilot Workstations

We used six simulation pilot workstations. Each workstation consisted of a computer, keyboard, monitor, and communication equipment. Each simulation pilot had a display of traffic and a list of assigned aircraft. The simulation pilots had information regarding the current state and corresponding flight plan data for each of the aircraft they were operating. The simulation pilots also had the weather cells displayed on their workstations and could request deviations due to weather for the affected aircraft.

In previous studies, DESIREE controlled the emulation of technical and pilot delays. This created a situation where the simulation pilots were unaware of the status of an open Data Comm message. To provide the simulation pilots with message status information, the simulation pilot workstation contained additional windows to display incoming Data Comm messages (see Figure 13). The TGF normally auto-WILCOed uplinked messages after a delay of the simulated system and crew response including expected variability. If TGF determined that the clearance was not flyable, it responded with an ERROR message. The TGF displayed all uplinked messages as soon as received (flagged with the response that DESIREE would send after delay, so that the simulation pilot could respond to questions from controllers about the received message). If needed, the simulation pilot interface allowed an override of the TGF-selected response, so that the simulation pilot could UNABLE a clearance that would have been WILCOed, by clicking the button at the bottom of the window.

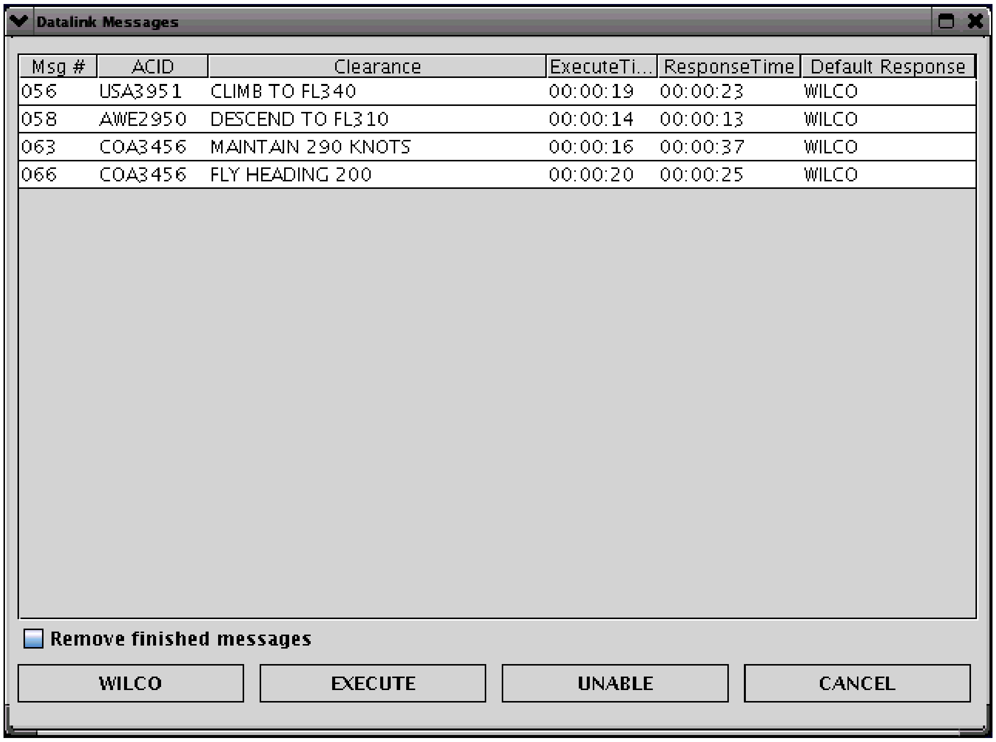


Figure 13. Data Comm messages window on a simulation pilot workstation.

2.5 Materials

2.5.1 Informed Consent Statement

Each participant read and signed an informed consent statement before the experiment (see Appendix B). The informed consent statement described the purpose of the study and the rights and responsibilities of the participants, and ensured participants that their data would be confidential and anonymous.

2.5.2 Biographical Questionnaire

Each participant completed the Biographical Questionnaire before the experiment. The Biographical Questionnaire contained questions regarding age, gender, and level of ATC experience (see Appendix C).

2.5.3 Post-Scenario Questionnaire

After completing each experimental run, the participants provided ratings about the effect of the data communication of the run on ATC tasks and communications on the Post-Scenario Questionnaire (PSQ). The participants also had the opportunity to provide responses to open-ended questions and to include other comments about the scenario that they considered relevant (see Appendix D).

2.5.4 Exit Questionnaire and Debriefing

The participants completed an Exit Questionnaire after completing the entire simulation. On the questionnaire, the participants rated the effect of experimental factors (such as service priorities, failure modes, and communication system delays) on controlling traffic. We also asked them to evaluate each of the data communication requirements and the degree of fidelity of the experiment. They also commented on aspects of the simulation that they found relevant (see Appendix E).

2.5.5 ATC Observer Rating Form

After each experimental run, two SMEs used a modified version of the Observer Rating Form (ORF; Sollenberger, Stein, & Gromelski, 1997; Vardaman & Stein, 1998) to rate the teams' performance and their use of the procedures (see Appendix F). The SMEs provided comments as necessary to support their ratings. Each SME filled out the form independently.

2.6 Airspace

We used a sector of generic airspace (Guttman& Stein, 1997). Guttman and Stein found that CPCs considered the generic airspace to be realistic and that their performance in the generic airspace was comparable to their performance in real airspace. Using generic airspace allowed researchers ensure that participants were equally familiar with the airspace. This also made it possible for us to apply the results to other different en route airspace environments.

We used the generic high-altitude sector (ZGN08) in this simulation (see the shaded section in Figure 14). ZGN08 had a roughly rectangular shape that extends for approximately 120 nm (222.24 km) from North to South, approximately 100 nm (185.2 km) from East to West, and from FL240 and up. It contained several intersections that contributed to sector complexity. ZGN08 was above and north of a low altitude en route sector, ZGN18. ZGN18 contained two metering fixes for aircraft that transitioned into the terminal sector to GEN airport.

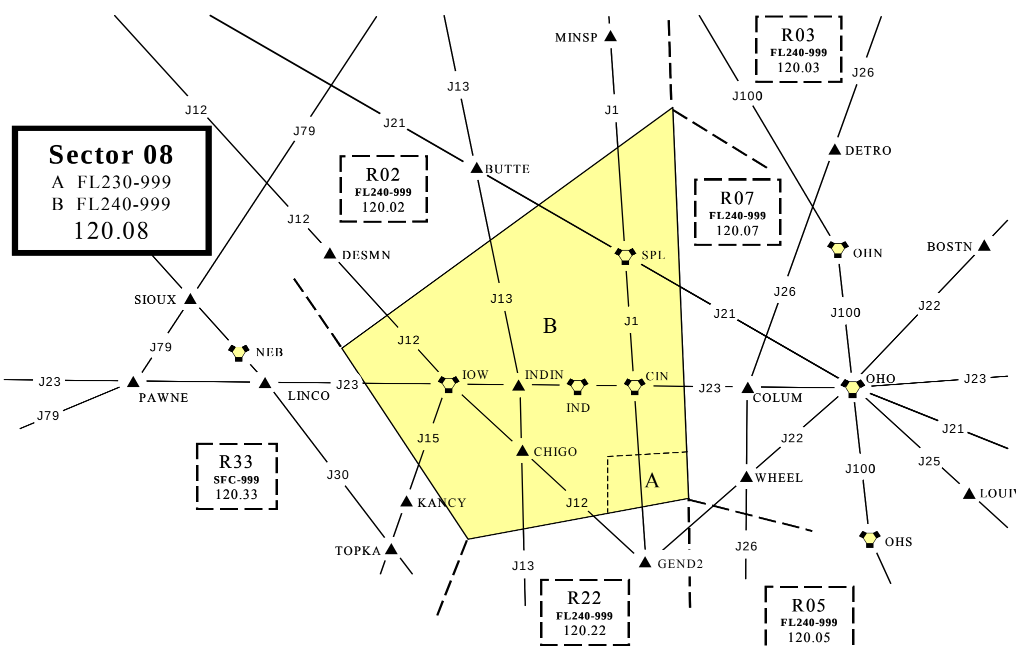


Figure 14. Schematic depiction of generic high-altitude sectors.

2.7 Traffic Scenarios

We used basic scenarios early in training to acclimate the participants to the systems, features, and procedures. These training scenarios lasted 30 minutes and had four traffic levels (with 8, 12, 16, and 24 aircraft). They were the same scenarios but with different call signs for the aircraft. The scenarios of the experimental runs started with approximately 16 aircraft and rose to a steady level of about 24 aircraft. Each experimental run lasted 50 minutes. The Peak Instantaneous Aircraft Count (PIAC) of 24 corresponds to 150% of the Monitor Alert Parameter (MAP) of 16 for ZGN08.

To ensure that controllers used a range of messages, we scripted scenarios in a way that required specific interventions. One was a weather pattern that required controllers to reroute aircraft. Another was time-based metering to a specific metering reference point, as controllers encountered in the field when managing tailored arrivals. We also included crossing traffic streams, overtaking traffic, and delayed clearances for continuing a climb inside the sector.

2.8 Experimental Design

2.8.1 Independent Variables

We determined the independent variables for the HITL simulation based on the Data Communications Segment 1 and Segment 2 research priorities, review of prior Data Comm studies, and group discussions that occurred at the HMI Summit in October 2008. Results from the en route cognitive walkthrough the Segment 2 research team conducted in June 2008 (George Mason University, 2008) also resulted in several research topics. In the following sections, we describe the independent variables as well as the research questions. We also describe existing assumptions for the research question.

2.8.1.1 Human-Machine-Interface/Display Design and Message Management

Designing an effective HMI for the R- and D-side controllers is critical to the success of Data Comm as a system for controller-to-pilot communications. Incorporated into this design challenge is the integration and interoperability that will enable the controller to manage voice-only and Data Comm aircraft from a single interface. In search of an optimal HMI design, we evaluated four different designs: Keyboard, Template, Graphical, and Combined modes. The *keyboard* entry capability is available in the ERAM system. We included a *template* that might be useful to create complex clearances similar to the method used by the Advanced Technologies and Oceanic Procedures (ATOP) system. Our participant controllers could construct Data Comm messages via a *graphical interface*, where they graphically interacted with the interface to manipulate an aircraft's position more easily than with other modes (e.g., to cross a fix at a particular altitude). Finally, we included a *combined* mode condition, where controllers could use the suite of interface options (i.e., keyboard, template, and graphical interfaces).

Research Questions

- What is the most effective display design for the Data Comm HMI?
- What input modalities result in the best controller performance for specific messages (e.g., speed and accuracy)?

Assumptions

- Users will get familiar with common display usability constructs (e.g., pop-up windows, pull-down menus, scroll bars, and navigation) and will receive training prior to the experimental simulations.
- The HMI must support mixed-mode operations; that is, some aircraft will not have Data Comm capability, and the controller will still use voice to communicate with Data Comm equipped aircraft for tactical communications and in case of Data Comm failure.

2.8.1.2 Data Comm Equipage Levels

We exposed controllers to several equipage levels. *Zero percent* equipage levels served as a baseline to mimic current operations. Previous research showed a benefit when 20 percent of aircraft were Data Comm capable,[1] but we used *10 percent* to determine whether it was still possible to derive a benefit with a lower level of Data Comm equipage. Conroy (2003) reported that controllers' maintaining a balance between safety and acceptable levels of performance (e.g., workload) was most vulnerable when equipage levels were 50%. He derived his conclusion from a fast-time simulation and not an HITL, which motivated us to include a *50 percent* equipage level. Finally, *100 percent* equipage assumes a controller is managing aircraft exclusively in High Performance Airspace (HPA) in Segment 2.

Research Question

- How does controller performance change when managing aircraft of varying mixed equipage environments?

2.8.1.3 Service Priorities

The FAA has proposed to provide incentives for early adopters by moving from the concept of *FCFS* to *BEBS*. We created BEBS procedures and investigated how this affected controller performance.

Research Question

- How does a change in priorities from FCFS to BEBS affect human performance in a Data Comm environment?

2.8.1.4 Flight Management System Integration

An aircraft equipped with a fully integrated FMS (in our case with Data Comm) could have a (modified) flight plan or other information (e.g., weather) message loaded automatically into the FMS to await manual pilot execution. We evaluated two proportions of FMS integration. At *50 percent,* half of the aircraft had FMS integrated. In contrast, we may see *100 percent* FMS integration when aircraft traverse through HPA in the Data Comm Segment 2.

Research Question

- How do changing proportions of FMS integration affect controller performance in a Data Comm environment?

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[1] From the 11/12/08 discussions between the Benefits, Segment 1 and Segment 2 research teams, and the RDHFL.

2.8.1.5 Failure Modes and Recovery

Data Comm malfunction may disrupt controllers and pilots maintaining the balance between system safety and efficiency, thereby adversely affecting controller performance and capabilities. We evaluated four levels of failure: No failure, individual aircraft failure, partial airspace failure, and total airspace failure. *No failure* represented the condition where all data communication messages exchanged between a controller and a pilot arrived at their destination. The information exchange failed if the airborne equipage of an *individual aircraft* failed, which represented *aircraft failure*. In a *partial airspace failure,* part of a sector lost its Data Comm capabilities. At the most extreme level, *a full system failure* precluded Data Comm capability in the sector, and controllers had to use voice communication for all aircraft.

Research Questions

- How does the magnitude of a Data Comm failure affect controller performance?

Assumptions

- Controllers will be able to stop traffic in other sectors from entering their sector as an option to cope with the Data Comm failure.
- Voice communication will be available as an alternative to Data Comm during a failure.
- Aircraft Communications and Reporting System (ACARS) will be part of the overall Data Comm system in Segment 2, thereby eliminating ACARS as a possible replacement for air traffic Data Comm in the event of a failure.

2.8.1.6 End-to-End Message Delays

One of the differences between the Segment 1 and Segment 2 Data Comm environments is the expected change in communication system delay. We implemented the delays according to the Segment 1 requirements that 95% of the messages had a one-way technical delay of less than 8 seconds for critical messages. Although, initially, the Communications Operating Concept and Requirements (COCR) document showed that the technical delay would change between Segments 1 and 2, subsequent discussions suggested that the technical delay would not change (EUROCONTROL/FAA, 2006).

To mimic a delay, we kept the technical delay from our simulator constant, but we modified the pilot delay. Our justification for this approach is that even with a constant technical delay, the flight deck may change in Segment 2 in a manner that would enable pilots to respond more quickly to Data Comm messages, resulting in a reduction of the round-trip message delay. Figure 15 shows the distribution of technical delays across all messages used in this experiment.

We created the distribution by running our delay determination algorithm 100,000 times. We set the maximum delay time to 17 seconds to meet the 95th percentile requirement based on the SC-214 documents. We set the minimum technical delay time to 2 seconds and applied the shape of the technical delay times from data collected when CPDLC Build 1 was operational at Miami Center.

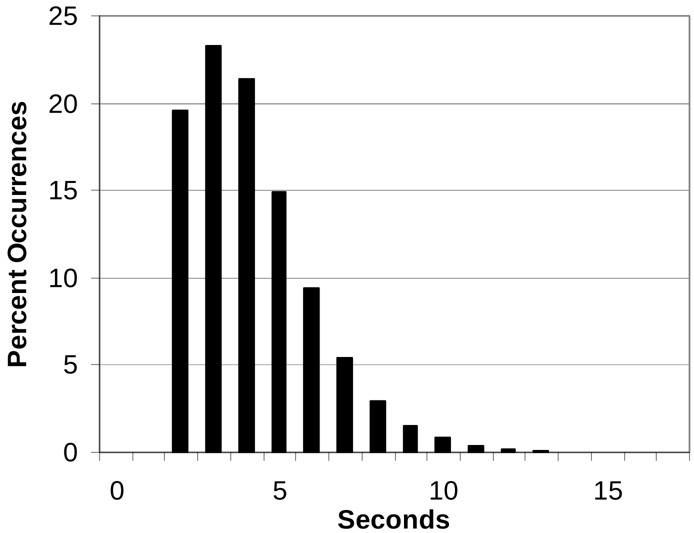


Figure 15. Percent occurrences of messages as a function of technical delay (in seconds).

We used the same approach to create pilot delay times. The SC-214 document provides a 95th percentile requirement for pilot responses as well. Figure 16 displays the simulated pilot delay distribution for Segment 1 for pilots that used an aircraft equipped with an integrated FMS. To meet the requirements, we set the minimum pilot delay time at 15 seconds and the maximum delay time at 98 seconds.

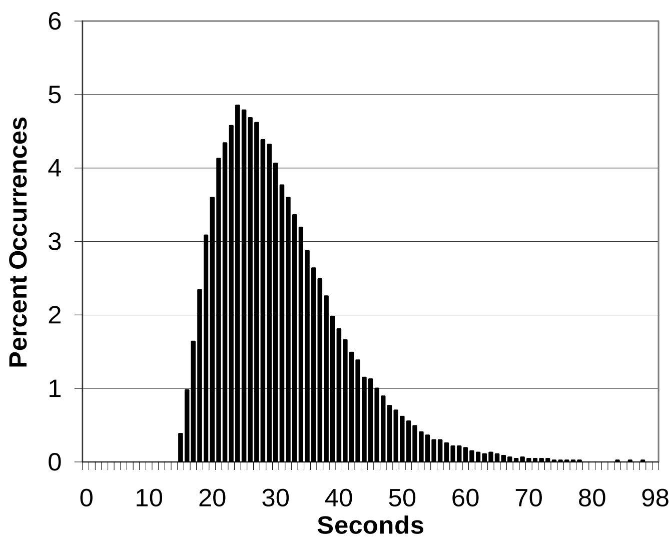


Figure 16. Percent occurrences of messages as a function of pilot delay for Segment 1 with an integrated Flight Management System (in seconds).

To emulate en route Segment 2 delays, we used pilot delays as specified for the terminal area in the SC-214 document. Our assumption is that the technical delays will not change between Segment 1 and Segment 2. However, because pilots will be using data communications services more frequently, they may request to move the data communications related display and controls within their primary field of view and within easy reach. These changes in return may lead to faster pilot response times. The shape of the distribution remained the same. In a similar manner, we increased the pilot delay times by 30% for aircraft that did not have an integrated flight management system.

In the previous paragraphs and figures, we addressed the designed technical delays and pilot response times of the simulated data communications system. In the following section, we present the realized round-trip message delays that controllers encountered during the experiment. The delays discussed here are for our baseline condition (i.e., all aircraft had Segment 1 en route pilot response times, had met technical delays specified in the SC-214 requirements, and had an integrated FMS). The mean delay of 25,595 messages was 39 seconds with the standard deviation of 10.4 seconds. The median of the delays was 37 seconds. The 95th percentile was 58 seconds (see Figure 17).

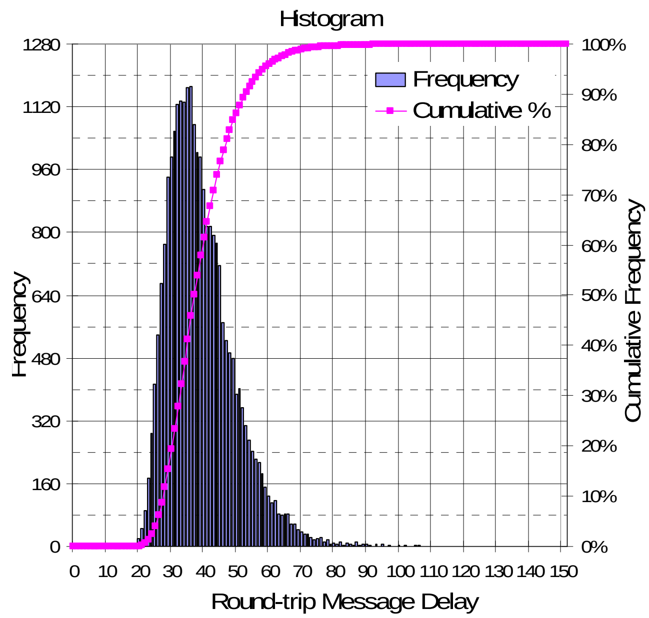


Figure 17. Round-trip message delay frequency counts and cumulative frequency distribution.

Research Question

- How does the Data Comm system delay of a message affect controller performance?

2.8.2 Experimental Manipulation

With limited resource and time, we could not use a full factorial design to test all independent variables. We used a fractional design. For each data collection session, four controllers participated as two teams of R- and D-side controllers. We assigned teams to one of two groups, Group A and Group B (see Table 2). We planned to have six groups of two teams of two controllers who worked as R- and D-sides (see Table 2).

Table 2. Teams, Positions, and Assignments

Team	R-side Participant	D-side Participant	Group
T1	R01	D02	A
T2	R03	D04	B
T3	R05	D06	A
T4	R07	D08	B
T5	R09	D10	A
T6	R11	D12	B
T7	R13	D14	A
T8	R15	D16	B
T9	R17	D18	A
T10	R19	D20	B
T11	R21	D22	A
T12	R23	D24	B

In the main experimental design, all controllers participated in all four levels of the HMI and equipage variables. To address the independent variables without the need for a large number of simulations scenarios, we exposed half of the teams to BEBS conditions and exposed the other half to FMS Integration changes (see Table 3). To limit the number of independent variables, we held certain parameters constant across all conditions (see Table 4). We will provide more details about each of the treatments in the following sections.

Table 3. Independent Variables

Variable	Level 1	Level 2	Level 3	Level 4
HMI	Keyboard	Template	Graphical	Combined
Equipage Levels	0	10	50	100
FMS Integration	50	100		
Failure Modes	No Failure	Individual-A/C Failure	Partial Failure	System Failure
Service Policies	First-come, First-served	Best-equipped, Best-served		
End-to-End Technical Delay of Messages	Segment 1	Segment 2		

Note. HMI = Human-Machine Interface; FMS = Flight Management System.

Table 4. Constant Parameters of Operation

Parameter	Value
Roles and Responsibilities	Controllers worked in two-person teams; one as R-side, one as D-side.
Traffic Level	On average 150% of current 2008 Monitor Alert Parameter shows level.
Training	All participants received the same instruction and materials, and worked through the same training scenarios.

2.8.3 Design of Experimental Runs

In this section, we describe the levels of independent variables and their assignment to experimental runs. In comparing different levels of an independent variable, we kept other independent variables constant. We described these in the left corner in each table. For instance, in the experimental runs that we used to compare four HMI modes, 50% of the aircraft in the sector had Data Comm capability, all aircraft had an integrated flight management system, no Data Comm failure occurred, and all aircraft were under the FCFS procedure.

The runs listed in the table have three-character codes: The first letter identifying Group A or Group B and a two-digit number identifying an experimental run. This two-digit number identified a unique scenario that had a predefined combination of independent variables, not the sequence of experimental runs. If they appeared in the previous table(s), we entered them in *italics*. All participants had 12 experimental runs that had various experimental conditions. Depending on the assignment, some participants had certain conditions that other participants did not encounter. In short, our experimental design was a fractional repeated design.

2.8.3.1 Workstation Human-Machine Interface

We compared HMI modes with the first four experimental runs (see Table 5). In the Keyboard HMI, controllers used special key sequences to construct complex messages that did not exist in ERAM. Using Data Comm, controllers could uplink simple clearances. They could perform it by using the ERAM Fly Out menus (FOMs) when the ERAM is available to them in the field. With the Template HMI, controllers could construct complex clearances in a dedicated window by selecting prototype messages (i.e., templates) and filling in the blanks with flight parameter values (as shown in Figure 2). In the Graphical HMI, we had Trajectory Data Blocks (TDBs) with altitude, speed, route, and time-dimension information that led to a trajectory display. With FOMs from the TDBs (as shown in Figure 3), controllers could create complex clearances and crossing restrictions. In the Template and Graphical modes, participants could use most keyboard functions, except those that included concatenated messages, BY, AT (time), AT (position), XC (position), AT (altitude), AT (speed), AT (time).

Table 5. Workstation Interaction Mode Experimental Design

	Data Comm Interaction	**Runs**
Equipage = 50%, FMS 100% Integrated, FCFS, No Failures, Segment 1	HMI1 – Keyboard	A01 B01
	HMI2 – Template	A02 B02
	HMI3 – Graphical	A03 B03
	HMI4 – Combined	A04 B04

Note. FMS = Flight Management System; FCFS =First-come, First-served; HMI = Human Machine Interface.

When comparing the HMI modes, we kept other independent variables constant: Fifty percent of the aircraft in the airspace were Data Comm equipped, all aircraft had an integrated FMS, and no Data Comm failures had occurred (as shown in Table 5).

Thus, to force the participants to use advanced Data Comm features through a particular HMI option, they had to create the following messages, with only that HMI option (see detailed descriptions of the message set in Appendix A).

- Concatenated messages.
- Messages that contained a BY option
  (e.g., CLIMB TO REACH FL350 BY CHIGO).
- Messages that contained an AT option
  (e.g., AT [time] CLIMB AND MAINTAIN FL350 or AT [position] DESCEND AND MAINTAIN FL240).
- Messages that contained an XC option
  (e.g., XC CHIGO AT FL240 or XC CHIGO AT 270 KNOTS).

The detailed steps controllers need to enter using these modes are described in a separate document of Data Comm thin specifications. For example, in the Graphical mode, controllers could create waypoints (see Figure 18; item illustrated as a solid circle at the top center of the figure) by clicking and dragging the mouse. They could use them to reroute aircraft. The dotted lines in Figure 18 show the new route for NWA2357. A 4-dimensional Trajectory Data Block (4DB) was attached to the waypoint. It showed the information of the waypoint position and altitude, the expected speed of the aircraft over the waypoint, and the expected arrival time of the aircraft over the waypoint. Once the controller selects it, the dotted line will become solid and become a new route for the aircraft. It had the time dimension in addition to three physical dimensions. A controller could click the second line (altitude field) to bring out a FOM for complex clearances and crossing restrictions. Waypoints could be removed by a single right-button press.

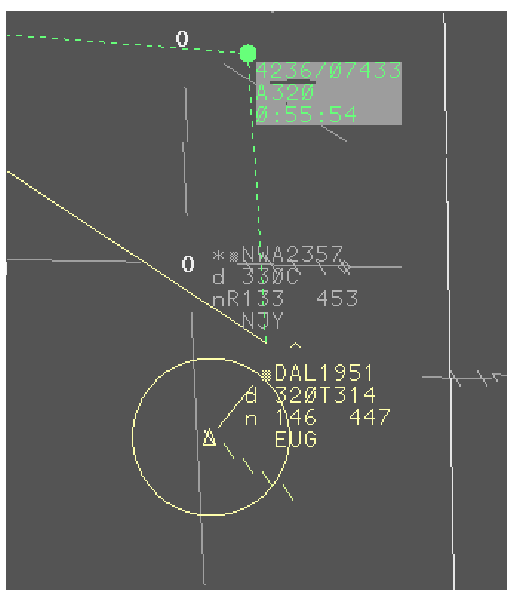


Figure 18. The 4-D Trajectory Data Block of a waypoint and a new route created for the aircraft NWA2357.

2.8.3.2 Data Comm Equipage Level

All participants experienced all equipage levels using the FCFS procedure to characterize the effects of equipage on controller performance. We included the 10% Equipage Level to address the specific research question, raised by the Data Comm Benefits Group, about benefits of Data Comm at low equipage levels. We kept the other independent variables constant: All conditions had aircraft with Data Comm equipment, integrated FMS, Combined HMI, and FCFS without any Data Comm failure (see Table 6).

Table 6. Equipage Level Experimental Design

	Equipage (%)	**Runs**
FMS 100% Integrated, HMI Combined, FCFS, No Failures, Segment 1	0	A05 B05
	10	A06 B06
	50	A04 B04
	100	A07 B07

Note. FMS = Flight Management System; HMI = Human-Machine Interface; FCFS = First-come, First-served.

2.8.3.3 Service Policy x Equipage Level

The six teams of Group A participated in this subset, comparing FCFS and BEBS procedures at two equipage levels. Integration level and HMI were constant: FMS 100% integrated and combined HMI (see Table 7).

Table 7. Service Policies x Equipage Level Experimental Design

FMS 100% Integrated, HMI Combined, No Failures, Segment 1, Group A		**Equipage (%)**	
		10	50
Service Policies	FCFS	A06	A04
	BEBS	A08	A09

Note. FMS = Flight Management System; HMI = Human-Machine Interface; FCFS = First-come, First-served; BEBS = Best-equipped, Best-served.

2.8.3.4 FMS Integration x Equipage Level

Group B participated in another design under four additional conditions; 50% or 100% of Data Comm by 50% or 100% FMS (see Table 8). With the integrated FMS, clearances were preloaded directly from the data communications system. Without it, pilots must manually key in data after receiving a Data Comm message from the controllers.

Table 8. FMS Integration x Equipage Level

HMI Combined, FCFS, No Failures, Segment 1, Group B		FMS Integration (%)	
		50	100
Equipage %	50	B08	*B04*
	100	B09	*B07*

Note. HMI = Human-Machine Interface; FCFS = First-come, First-served.

2.8.3.5 Data Communications Failures Type

All controllers experienced the data communication failure by individual aircraft. The individual aircraft failures occurred around 8, 14, 23, 28, 37, and 43 minutes after the start of the experimental run.

The teams in Group A encountered partial failure, where a part of the sector lost its Data Comm capabilities. An example would be a single transmitter failure. The other teams from Group B encountered a full Data Comm System failure, where all aircraft in the entire sector lost Data Comm capability (see Table 9). To prevent participants from experiencing too many failures, we designed the sequence of simulations in such a way that the failure occurred after several days of training and experimental runs. By exposing each group to either a partial failure or a system failure, each participant saw only two failure conditions (one individual and one more extensive, either partial or total). The partial and total failures occurred around 30 minutes after the start of the experimental run.

Table 9. Failure Type

	Failure Type	Runs
FMS 100% Integrated, FCFS, Equipage 50%, Segment 1	None	*A04* *B04*
	Individual	A10 B10
	Partial	A11
	Full System	B11

Note. FMS = Flight Management System; FCFS = First-come, First-served.

2.8.3.6 End-to-End Technical Delay: Segment 1 vs. Segment 2

All controllers encountered two types of technical delay in each Segment, a shorter delay for the most time critical clearance messages, and a longer delay for other messages. In Segment 1 conditions, controllers experienced the 8-second, 95th percentile, one-way delays for critical messages and the 30-second 95th percentile, one-way delays noncritical messages (see Table 10). In Segment 2 conditions, controllers experienced the 5-second 95th percentile, one-way delay for critical messages and the 10-second 95th percentile, one-way delay for noncritical messages.

Table 10. Technical Delay

	Technical Delay	Runs
FMS 100% Integrated, FCFS, No failure, Equipage 50%	Segment 1 Delay	*A04* *B04*
	Segment 2 Delay	A12 B12

Note. FMS = Flight Management System; FCFS = First-come, First-served.

2.8.3.7 Scenarios Summary

Table 11 shows the number of experimental runs by groups and study conditions. Group A and Group B each ran two unique scenarios to allow comparison with baseline conditions without BEBS or FMS Integration, respectively.

Table 11. Number of Experimental Scenarios per Participant

	Group A	**Group B**
HMI	4	4
Equipage	3	3
Service Policies x Equipage	2	
FMS Integration x Equipage		2
Failure Type	2	2
End-to-End Delay	1	1
Total number of experimental runs	12	12

Note. HMI = Human-Machine Interface; FMS = Flight Management System.

We grouped the twelve experimental runs into three blocks: (a) HMI, (b) Equipage that included the Failure and End-to-End Delay scenarios, and either (c) Service policies x Equipage block or (d) FMS integration x Equipage block. The HMI block was first; we trained participants on each HMI alternative prior to the test scenario using that HMI. The combined HMI was always last. We counterbalanced the presentation orders of these blocks within the six teams in Group A and within the six teams in Group B (see Table 12).

Table 12. Counterbalancing of Blocks

	Test Series		
Team	**First**	**Second**	**Third**
1	HMI	Data Comm Equipage	Service Policy
2	HMI	Data Comm Equipage	FMS Integration
3	HMI	Service Policy	Data Comm Equipage
4	HMI	FMS Integration	Data Comm Equipage
5	HMI	Data Comm Equipage	Service Policy
6	HMI	Data Comm Equipage	FMS Integration
7	HMI	Service Policy	Data Comm Equipage
8	HMI	FMS Integration	Data Comm Equipage
9	HMI	Service Policy	Data Comm Equipage
10	HMI	FMS Integration	Data Comm Equipage
11	HMI	Data Comm Equipage	Service Policy
12	HMI	Data Comm Equipage	FMS Integration

Note. HMI = Human-Machine Interface; FMS = Flight Management System.

2.9 Procedure

2.9.1 General Schedule of Events

Four participants arrived at a time and worked in pairs over the 7 days of the simulation. In each team, one participant worked as the R-side controller responsible for ensuring aircraft separation, and one as a D-side controller providing assistance. Table 13 shows the first three weeks of the schedule. The first two teams arrived on the first Monday, the second two on the second Wednesday. A similar schedule was used for other teams. Table 14 displays a sample schedule of events for each group.

Table 13. General Schedule: First Three Weeks

	Monday	**Tuesday**	**Wednesday**	**Thursday**	**Friday**
Week 1	Teams 1 & 2 Travel In	Train	Train/Test	Train/Test	Train/Test
Week 2	Train/Test	fNIR	Teams 1 & 2 Travel out Teams 3 & 4 Travel In	Train	Train/Test
Week 3	Train/Test	Train/Test	Train/Test	fNIR	Teams 3 & 4 Travel Out

Note. The fNIR in the table is a part-task activity that Drexel University performed in conjunction with the current human-in-the-loop. fNIR = Functional Near Infrared.

Table 14. Sample Schedule of Events for One Group

Week 1							
Time	**Tuesday**	**Time**	**Wednesday**	**Time**	**Thursday**	**Time**	**Friday**
08:00	Introductions	08:00	Training Scenario 7	08:00	Training Scenario 13	08:00	Refresher
09:45	Break15	08:30	Break15	08:30	Break15	08:45	Break30
10:00	First Intro Scenario	08:45	Training Scenario 8	08:45	Training Scenario 14	09:15	Test Run 5
10:30	Break15	09:15	Break30	09:15	Break15	10:05	Break30
10:45	Training Scenario 1	09:45	Training Scenario 9	09:30	Training Scenario 15	10:35	Test Run 6
11:15	Break15	10:15	Break30	10:00	Break30	11:25	Lunch
11:30	Training Scenario 2	10:45	Test Run 1	10:30	Test Run 3	12:25	Test Run 7
12:00	Lunch	11:35	Break15	11:20	Break15	13:15	Break30
13:00	Training Scenario 3	11:50	Training Scenario 10	11:35	Training Scenario 16	13:45	Test Run 8
13:30	Break15	12:20	Lunch	12:05	Lunch	14:35	Break30
13:45	Training Scenario 4	13:20	Training Scenario 11	13:05	Training Scenario 17	15:05	Test Run 9
14:15	Break15	13:50	Break15	13:35	Break15	15:55	End of Day
14:30	Training Scenario 5	14:05	Training Scenario 12	13:50	Training Scenario 18		
15:00	Break15	14:35	Break30	14:20	Break30		
15:15	Training Scenario 6	15:05	Test Run 2	14:50	Test Run 4		
15:45	End of Day	15:55	End of Day	15:40	Debrief		
				16:10	End of Day		

Week 2			
Time	**Monday**	**Time**	**Tuesday**
08:00	Refresher	08:00	fNIR Training Scenario
08:30	Break30	08:10	fNIR n-back
09:00	Test Run 10	08:20	Break10
09:50	Break15	08:30	fNIR Test Run 1
10:05	Training Scenario 19	08:40	Break10
10:35	Break15	08:50	fNIR Test Run 2
10:50	Training Scenario 20	09:00	Break10
11:20	Break15	09:10	fNIR Test Run 3
11:35	Training Scenario 21	09:20	Break30
12:05	Lunch	09:50	fNIR Test Run 4
13:05	Test Run 11	10:00	Break10
13:55	Break30	10:10	fNIR Test Run 5
14:25	Test Run 12	10:20	Break10
15:15	Debrief -Long	10:30	fNIR Test Run 6
16:15	End of Day	10:40	Debrief
		10:50	End of Day

Note. End of day included a daily debriefing of participants. fNIR = Functional Near Infrared.

2.9.2 Initial Briefing

After the participants signed the informed consent statement and filled out the biographical questionnaire, we briefed them on the schedule, purpose, and procedures of the experiment. The SMEs briefed the participants on the airspace, Standard Operating Procedures (SOPs), Letters of Agreement (LOAs), and Data Comm message set.

2.9.3 Practice Scenarios

Airspace and Data Comm training took place over 12–15 practice scenarios (6–8 hours), as shown in Table 14. We instructed the participants about all procedures that would be in effect and described any special elements in the following scenario. They used the WAK during training. The two participants who wore the oculometer for the test runs also wore it during the last training scenario to become accustomed to the device prior to the test run.

2.9.4 Procedure

To accommodate our experimental design, we needed at least six groups of two teams of two controllers who worked as an R-side and a D-side. That is, from four participants, we created two teams of R- and D-side controllers. Four controllers participated simultaneously as a group.

Before each test scenario, the experimenters informed the participants of the relevant information for the following experimental run such as HMI mode and Data Comm equipage level to be in effect. After the participants received all of the instructions and the experimenters answered any questions from the participants, we began the 50-minute experimental runs. One team of each group wore the oculometer in all experimental runs. We instructed the participants to enter their workload ratings on the WAK every 2 minutes. During the experimental runs, two SMEs (one for each team) overseeing controllers' interactions with the ATC system evaluated controller performance using an OTS form (see Appendix F).

During the experimental run, we collected all controllers' and system responses. We audio and video recorded controllers' activities and audio recorded pilots' interactions with the controllers. We recorded all controllers' and pilots' interactions with the system. We collected eye movement data from half of the participants. We recorded fNIR data from all participants during the experimental runs. For fNIR data collection, we asked the participants to stay stationary about 20 seconds for the baseline measurement before the start of the experimental run. We used this measurement for normalizing their fNIR data that we collected during the experimental run.

After each experimental run, the participants completed the PSQ. They took a break for about 20 minutes before the next run. After finishing the HMI test series, the participants completed the HMI questionnaire in the Exit Questionnaire package (see Appendix E) and discussed the features of the HMI designs. Once the participants finished all experimental runs, they completed the Exit Questionnaire. The experimenters conducted a final debriefing to discuss the simulation, the systems, the procedures, and their effects on Data Comm as well as any additional system or interface tools for Data Comm.

2.9.5 Data Handling Procedure

We assigned a coded identifier to each participant and used it for anonymity of the data. We tagged all data collection forms, computer files, electronic recordings, and storage media with the coded identifier to conceal the identifiable information of the participants.

3. RESULTS

We present the results under each of the research questions addressing different data communication interfaces: HMI modes (Keyboard, Template, Graphical, and Combined), Data communication equipage levels (0%, 10%, 50%, and 100%) of the aircraft in the sector, Service priority differences (FCFS vs. BEBS), FMS integration, Data communication failures (individual aircraft failure, partial space failure, and total space failure), and Communication system delays (Segment 1 and Segment 2). We addressed each of these questions with PTT, workload ratings, questionnaire responses, Exit Questionnaire responses, clearances issued to aircraft, and participants' comments. We also analyzed the data of eye movements, aircraft durations and distances flown in the sector as efficiency measures, controllers' entries, and fNIR. We could not finish analyzing them for all research questions; thus, we entered the finished analyses in the relevant research question sections. For eye movement data, we had missing data that did not warrant inferential statistical testing for many of the research questions. Therefore, we summarized the results separately at the end of the results section. Before presenting the results, we describe our preparation of the data analysis and the general characteristics of the data presented in this report.

3.1 Characteristics of Data and Data Analysis Procedure

We used parametric tests for objective data, such as PTT, controllers' commands and clearances, fNIR, time and distances, and repeated measure Analysis of Variance (ANOVA) tests for overall tests and pairwise tests to follow up the overall significant results.

We used nonparametric tests for questionnaire ratings because of the small sample size and missing data: Friedman test as a substitute of the repeated measure ANOVA and Wilcoxon Matched-Pair Rank tests for post hoc pairwise comparisons. These nonparametric tests do not have to meet the normal distribution assumption or a large sample size, which is required for the use of parametric tests. We tested the differences between levels (e.g., combined, keyboard, graphical, and template) of a variable (e.g., HMI mode), which we measured multiple times; that is, our participants used them all. The Friedman test uses ranks across the levels of the variable and tests its statistics value against a chi-square distribution. As a post hoc test to follow up the significant Friedman test results, we used two-tailed nonparametric Wilcoxon Matched-Pair Rank tests. It calculates the difference between two variables, ranks the absolute values of them, and sums the positive and negative ranks. Then it uses the z distribution to test their significance. We did not plan specific comparisons. Therefore, we used the Friedman test first, and then we used the Wilcoxon Matched-Pair Rank tests. For both tests, we used SPSS Version 14 statistical package (SPSS, 2005). For the Wilcoxon Matched-Pair Rank tests, SPSS used the sum of the negative ranks against the z distribution. Thus, all of the z values shown in the following tables were negative. We did not control the α level for pairwise comparisons because our purpose was to see the patterns of controllers' questionnaire ratings in addition to observing the statistical significance in a strict manner. For instance, when we had four levels, there were six pairs to compare. When we controlled the overall pairwise comparison at $\alpha = .1$ for six pairs and controlled each pairwise comparison at $\alpha = .0167$, most probabilities of the pairwise comparisons did not reach .0167 but were close. In this report, we describe pairwise comparisons as significant when their probabilities were less than .05. The overall α for six comparisons at .05 is .30 for six comparisons.

3.1.1 Push-To-Talk

We calculated the number and mean duration of PTT events for each simulation scenario and introduced a between-group independent variable (Actor) for controllers and pilots. For each of the experimental blocks we selected the appropriate scenarios and arranged the dependent variables in a format that enabled us to conduct a mixed (between groups and repeated measures) analysis.

3.1.2 Workload

Preliminary analyses indicated that latencies for responses to WAK prompts were similar across conditions. We therefore did not analyze latencies further. There was a rather high incidence of missing values; 11.3% overall, but initial analyses also showed that differences in proportion of missed responses across conditions were not significant.

Some test runs ended before a 24th or 25th WAK probe was presented, so for all analyses reported, we used only the first 23 WAK events presented at 2-min intervals from 00:02 to 00:46 in each 50-min test run.

A preliminary analysis examined the average rating across teams and conditions by probe position, excluding data communication Failure conditions. We used the following three measures to record traffic levels:

1. Aircraft on frequency for Sector 8.
2. Aircraft geographically within Sector 8.
3. Aircraft either on frequency or within the sector, or both.

Figure 19 shows the plots of all three of these measures along with average subjective workload ratings Traffic levels ramped up to the nominal 150% MAP value during the first few minutes of the test scenario. Figure 19 also shows that subjective workload correspondingly rose rather quickly during the first 10 minutes of the run. There is also a falloff in traffic level in the last 10 minutes of the scenario. We assume this must have contributed to the similar decrease in workload ratings during that period.

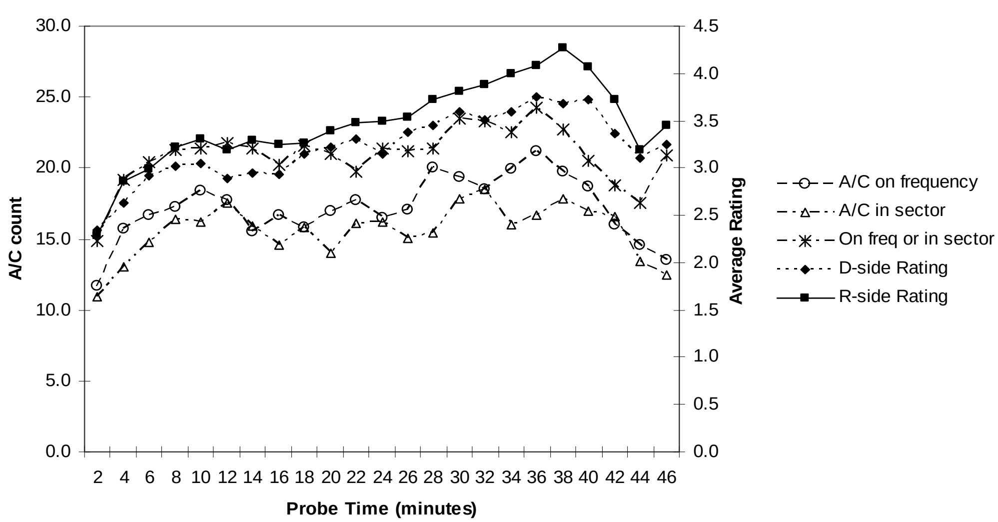


Figure 19. Average traffic levels and WAK workload ratings vs. scenario time.

Average ratings are low to moderate, with the peak at 4.2, for the R-side at 38 minutes; R-side ratings were higher (in average by about 0.3 points) than the D-side. Workload ratings of Data-side controllers correlated strongly with those from Radar-side controllers, Pearson $r = 0.97$. Therefore, for the statistical analysis of the aircraft counts, we averaged the WAK ratings of both controller positions and used team averages. We correlated each of the traffic-level measures to team-average workload ratings; see Table 15 for the results. Traffic level explained about half of the variance of average ratings (r^2).

Table 15. Correlations of Traffic Measures with Average Subjective Workload

	Pearson *r*	***p***	r^2
Aircraft on frequency	.778	< .001	.61
Aircraft in sector	.692	< .001	.48
Aircraft on frequency or in sector	.711	< .001	.51

The large number of missing ratings might simply be due to forgetting, but they might also have resulted from controllers being too busy to respond to the WAK prompt before the probe timed out. We calculated correlation coefficients for average workload ratings and number of missing ratings; the relationships were moderate for the D-side controllers ($r = .56$, $p < .01$) and for the R-side controllers ($r = .36$, $p < .05$).

We wanted to know if the initial training of participant controllers was sufficient to achieve proficiency in using data communications. If controllers were still putting effort into learning new features during early test runs, we would expect them to report higher workloads initially, declining as they gained proficiency. This effect would be superposed on any effects of experimental conditions. The counterbalancing of experimental conditions isolates them from time- or sequential-order effects, but practical considerations prevented us from fully counterbalancing all treatments. The exceptions were as follows:

1. Test Runs 1 through 4 were always the HMI condition. The order of the Graphic, Keyboard, and Template HMIs was counterbalanced across Test Runs 1, 2, and 3 and, therefore, would not be confounded with any learning effect still present in early runs. The Combined HMI condition was the fourth test run for every team and, therefore, potentially confounded with a learning effect.
2. The System Failure or Partial-Airspace Failure test run was always the last run of the Equipage series so that participants would not overestimate the likelihood of outages during the series.

Therefore, we compared performance over test runs, omitting the Failure scenarios, and collapsing across all other experimental conditions (see Figure 20). Because the range of ratings used varied from participant to participant, we transformed the WAK ratings scores to *z*-scores by subtracting each participant's mean rating and dividing by the standard deviation. We replaced missing data with zero, the mean of the *z*-scores. The initial decline in subjective workload suggests that participants were still learning the airspace and the Data communication features after completing the initial training runs. The effect of Run was significant, $F(11, 242) = 3.215$, $p < .01$. Neither the main effect of Controller Position nor its interaction with runs was significant, so we pooled the data for the R- and D-sides for comparisons between pairs of runs. Test Run 1 was significantly different from runs 3, 4, 5, 6, 7, 8, and 11 by Tukey's HSD post hoc test at the $p < .05$ level; other comparisons were not statistically significant, because only the first test run differed significantly from the following runs. It is reasonable to suppose that the workload reports in later runs did not reflect any added component due to learning effort.

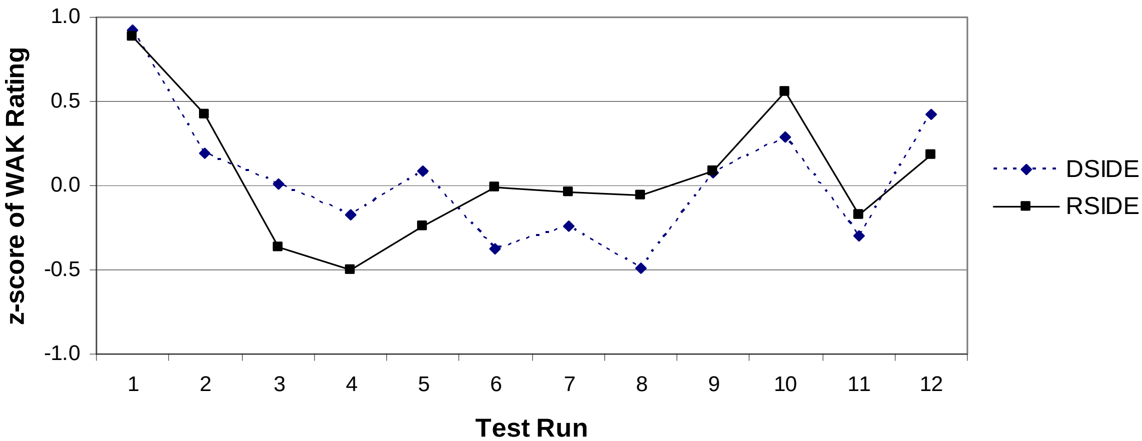


Figure 20. Subjective reported workload averaged over teams and conditions.

In general, controllers' subjective ratings of workload using the WAK keypad were rather low, considering that we set the traffic level to approximate 150% of the current MAP level (estimated by our SMEs). Also, the range of ratings given by controllers in a team tended to be narrow; the center of the range varied from team to team, however.

It is possible that we somewhat overestimated the MAP parameter for the sector as the participant controllers experienced it. The SMEs established the MAP value during scenario-development simulations when each traffic set was different from the previous one. Their workload tended to be high because (a) the software was still under development (occasional bugs occurred), (b) they were continuously evaluating traffic and flight plans for realism and conformity to proper procedures, (c) and they were controlling traffic. Participants always had the same test scenario (same set of flight plans and weather evolution), and participants had fewer glitches with hardware and software.

3.1.3 Questionnaires

We administered three questionnaires: PSQ (see Appendix D), HMI mode questionnaire (see Appendix E), and Exit Questionnaire (see Appendix E). We administered the HMI questionnaire just after the fourth experimental run because by then the controllers had experienced all four modes of HMI. Appendix E includes the HMI questionnaire as part of the Exit Questionnaire.

Because each of the questions in the questionnaires was unique we tested each of the questions individually. Although we considered their ratings close to the interval scale, we decided to use nonparametric statistics instead of parametric statistics because we did not have many participants and data points. For instance, we had 24 controllers total. Because half of them worked as R-side and the rest as D-side, the total number of data points in a group was12 for each question. Sometimes we had missing data among these, and the data did not have normal distributions. The drawback of using nonparametric statistics is that it has a limited capability in detailed statistical analyses, such as the analysis of interactions between multiple variables.

3.1.4 Aircraft Maneuver Data Analyses

The TGF managed the aircraft in the simulation airspace, based on inputs from pilots, controllers, simulation scripts, and rules. It recorded all input messages from controllers and pilots with timestamps and descriptive tags while the aircraft were on frequency for Sector 8 of Genera Center (ZGN08, at 120.080 MHz). We analyzed the data that the TGF used to change an aircraft's trajectory (route, altitude, speed and heading clearances, and crossing restrictions). Controllers could enter these clearances directly to aircraft equipped with Data Comm. We recorded the time that the clearance message was received by TGF. Controllers voiced clearances to pilots of aircraft that were not Data Comm equipped (and optionally to Data Comm-equipped aircraft, at their discretion). SimPilots read back the clearances and entered the commands using the keyboard.

We used two Data Comm equipage levels to investigate the effect of different equipage levels on FMS and service policy. This (using two equipage levels) presented problems because a higher level of equipage condition would lead to more Data Comm communications by controllers than the lower level of equipage condition.

We chose to compare the actual numbers of clearances against a model that took into account the equipage level with the following constraints (Model 1).

1. Controllers would issue the same total number of clearances of each type in all test runs since we used the same flight plans for all test runs except flight identifications, and the traffic was therefore comparable across runs.
2. Controllers would issue clearances using Data Comm if the aircraft was equipped. Otherwise they would use voice. Therefore, the proportion of Data Comm clearances relative to voice should match the proportion of equipped aircraft. This simple model fails in most analyses because it predicts that controllers will never issue clearances by voice in the 100%-Data Comm conditions; in fact, some voice clearances were issued to Data Comm-equipped aircraft. This was expected, as controllers are required by SOPs to use voice clearances for tactical separation of aircraft.

To improve the model, we added a parameter for an expected number of clearances always issued by voice message. This model (Model 2) has the following constraints:

1. Controllers issue the same total number of clearances of each type in all test runs, since the set of flight plans was the same for all test runs, and the traffic is therefore comparable across runs. The expected number of clearances per run is one-quarter of the total for all four runs, $C_T/4$.
2. Controllers always use voice for k number of clearances (e.g., tactical clearances). Again, since the traffic is comparable across runs, k is the same across runs.
3. Controllers issue the remaining $C_T/4 - k$ clearances per run using Data Comm if the aircraft is equipped, otherwise they use voice. Therefore the proportion of nontactical Data Comm clearances relative to voice should match the proportion of equipped aircraft.

We then compared actual numbers of clearances to the numbers predicted by the models. There would be no data communications for the 0% Equipage condition. Therefore, only equipage levels greater than zero (> 0) were included in the *goodness-of-fit* tests.

3.1.5 Eye Movement Data

Eye movement data was filtered on several levels. We included data that had a minimum of 12 eye fixations, within 2 inches or less and within 30 seconds or less, prior to eyes moving to another object.

3.1.6 Functional Near Infrared Data

The fNIR data collected during the simulations consisted of voltage levels registered by the fNIR sensors. We removed data from the voxels that displayed saturation due to contamination of the near infrared signal with ambient light. Scripts implemented in Matlab (The Mathworks Inc., 2010) filtered the data for motion artifacts. We then calculated average values of the processed data across each simulation run for each of the 16 voxels. When a voxel did not contain valid data (missing data), we substituted that observation with the grand mean for that channel.

3.1.7 Time and Distance (Efficiency)

As a measure of efficiency, we used time and distance of aircraft that traversed the sector. There are four definitions of ownership:

1. Aircraft are on the controller's frequency.
2. Aircraft are physically inside of the sector.
3. Aircraft are under the controller's responsibility. This starts when the controller accepts the handoff, and it ends when the aircraft physically leaves the sector.
4. Aircraft are under the controller's control. This starts when the controller accepts the handoff, and it ends when the next sector accepts the handoff from the current controller. Because of the time constraint, we could finish analyzing the effect of HMI and equipage levels only.

We used repeated measure ANOVA tests for the four HMI modes and four equipage levels. The unit of analysis for the time and distance data consisted of a team-flight combination, that is, each team manipulated each aircraft across a set of conditions. We used the same aircraft with different call signs in each experimental run. Thus, the distance flown and time spent in the sector by aircraft would have been the same if controllers controlled them in the same way. We assumed they might not. It could depend on a specific experimental condition. For instance, they might be able to direct aircraft at 100% Data Comm level more efficiently than 10% Data Comm level, and the overall distances aircraft flown and times spent by aircraft could be shorter in 100% Data Comm level than 10% Data Comm level.

3.1.8 Controllers' Entries

Because of the time constraints, we did not analyze Failure modes or Segment 1 vs. Segment 2 delays. We grouped the data into meaningful units, such as clearances, and tested the difference between HMI modes and equipage levels.

3.1.9 Over-The-Shoulder Ratings

We analyzed the ratings that the SMEs made on the OTS rating form to evaluate the participants' ability to maintain separation and resolve potential conflicts, sequence aircraft efficiently, use control instructions effectively and efficiently, and maintain an overall safe and efficient traffic flow.

For the pairwise comparisons, we used paired-*t*-tests to analyze results, using the *Bonferroni* correction for the experiment-wise α level at .05 and each comparison at α = .0016, because tests were not independent. We found no significant differences on any of the 31 ratings making up the ORF for individual aircraft failure, system failure, part-airspace failure, or end-to-end technical delay.

3.1.10 Debriefing Comments

We will discuss the debriefing comments based on groups, because we interviewed controllers during the exit debriefing as a group and not individually. When addressing the different topics, the individual controllers added to the discussion, but we will present the resulting comments by group.

3.2 Human-Machine Interface

3.2.1 Push-To-Talk

We conducted separate analyses on the number and the mean duration of PTT events as a function of HMI implementation. Using a univariate approach, the results indicated that pilots had more PTT events than controllers did (M = 166, SE = 4.7) and (M = 146, SE = 4.7), respectively, $F(1, 22) = 9.06$, $p < .05$. However, when applying the multivariate approach to the repeated measures analysis, we found that the differences in the number of PTT events between the levels of HMI did not reach statistical significance.

Figure 21presents the results in a bar chart. We have plotted the chart on a scale that encompasses the total number of PTT events in the voice-only condition, *350*. The mean duration of PTT events did not differ as a function of HMI implementation (M = 3.43, SE = 0.15 seconds).

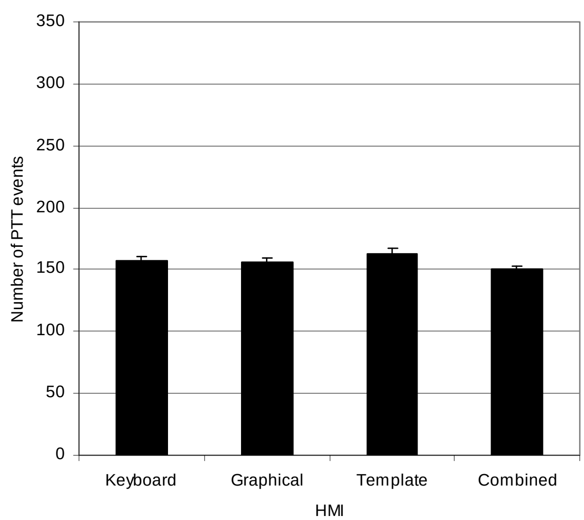


Figure 21. Number of PTT events as a function of HMI implementation. *Note.* The small line with a hat shows the magnitude of one standard error of the mean for each parameter.

3.2.2 Workload

Subjective ratings of workload did not differ significantly between R-side and D-side controllers. Differences between HMIs (see Figure 22) were significant, $F(3, 66) = 3.9749$, $p < .016$. The Tukey's HSD Post hoc comparisons showed significantly higher reported workload with the Template than with the Combined HMI, $p = .008$. Other comparisons were not statistically significant.

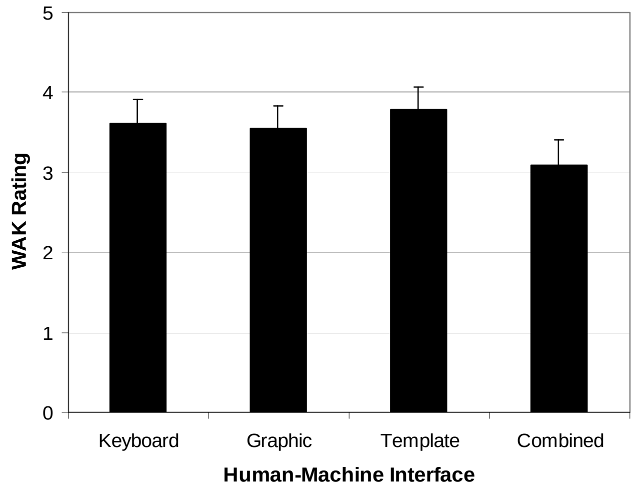


Figure 22. Average subjective workload for four HMI configurations.

3.2.3 Post-Scenario Questionnaire

The first part of the PSQ addressed the impact of the data communication interface on major ATC tasks (situation monitoring, resolving aircraft conflicts, managing air traffic sequences, routing or planning flights, assessing weather impact, and managing sector and position resources). Figure 23 shows that the R-side controllers' ratings for Situation Monitoring were significantly different among the HMI interfaces, Friedman test ($n = 12$), $\chi^2 = 1.750$, $df = 3$, $p = .008$.

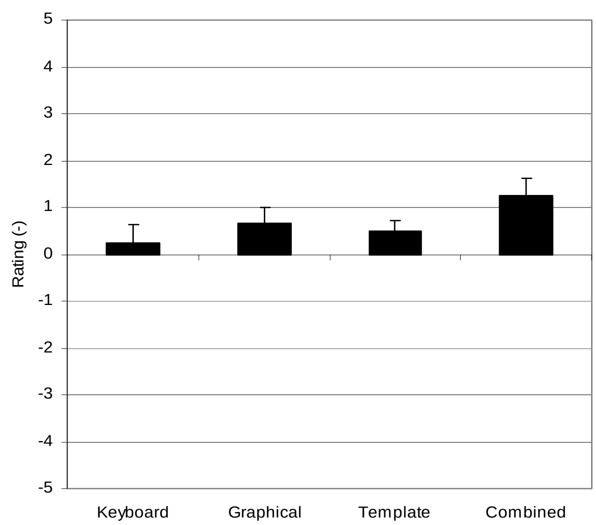


Figure 23. R-side mean ratings on situation monitoring with HMI interfaces.

Table 16 shows that the only significant differences were between Combined and Keyboard (z = -2.226, p = .026) and between Combined and Template (z = -2.460, p = .014). Overall, the results showed that the Combined mode helped controllers most in the situation monitoring task.

Table 16. Significant HMI Comparisons Test Results of R-side Ratings in the Post-Scenario Questionnaire

Tasks	**Friedman Test Results**		**Wilcoxon Test Results HMI Pairs**					
			K vs. C	**G vs. C**	**T vs. C**	**G vs. K**	**T vs. K**	**T vs. G**
Situation monitoring	χ^2 = 11.750, p = .008, n = 12	z	-2.226		-2.460			
		p	.026		.014			

Note. K = Keyboard; C = Combined; G = Graphical; T = Template.

For other ATC tasks (resolving aircraft conflicts, managing air traffic sequences, routing or planning flights, assessing weather impact, and managing sector/position resources), the Friedman tests did not show any significant rating differences across the HMI interfaces. For the D-side, there was no significant Friedman test result in any of the six questions (p> .05).

The second part of the PSQ (see Appendix D) was about ATC communications. We asked 17 questions. The only significant Friedman test for R-side was about Crossing Constraints at a Specified Altitude (χ^2 = 8.377, df = 3, p = .039). As Table 17 shows, the participants rated the Combined mode higher than graphical (Wilcoxon Matched-Pair Rank tests: z = -2.280, df = 3, p = .023), rated combined higher than template (z = -2.371, df = 3, p = .018), and rated graphical higher than template (z = -2.014, df = 3, p = .044). Overall, the Combined mode was preferred most (see Figure 24).

Table 17. Significant HMI Comparison Test Results in the Post-Scenario Questionnaire (R-side)

Tasks	**Friedman Test Results**		**Wilcoxon Test Results HMI Pairs**					
			K vs. C	**G vs. C**	**T vs. C**	**G vs. K**	**T vs. K**	**T vs. G**
Crossing constraints at a specified altitude	χ^2 = 8.377, p =.039, n = 9	z		-2.280	-2.371			-2.014
		p		.023	.018			.044

Note. K = Keyboard; C = Combined; G = Graphical; T = Template.

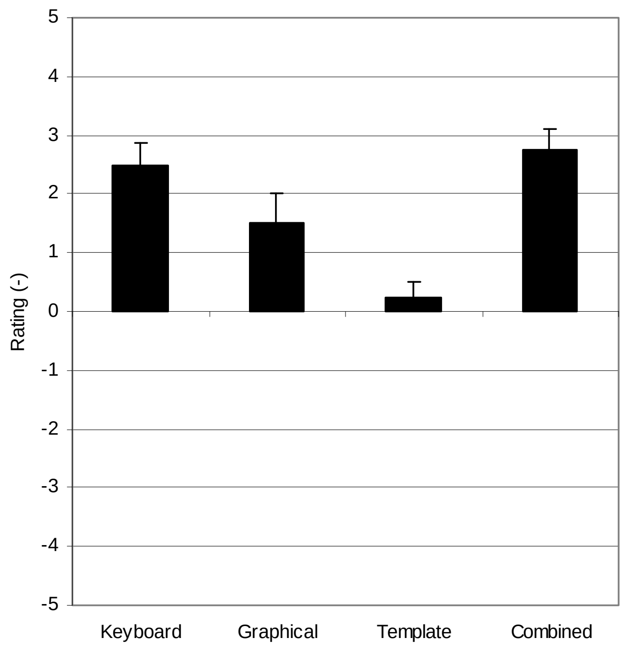


Figure 24. R-side controllers' average ratings on HMI modes for the task of crossing constraints at a specified altitude.

For the D-side controllers, the significant Friedman test results were for two questions (see Table 18; see also Figure 25 and Figure 26). One of the questions was about Current Route Modifications (n = 12, χ^2 = 9.256, df = 3, p = .026). The follow-up Wilcoxon Matched-Pair Rank test showed that they rated the combined higher than the keyboard (z = -2.251, df = 3, p = .024) and the combined higher than the template (z = -2.388, df = 3, p = .017). The other question was Crossing Constraints at a specified altitude (n = 12, χ^2 = 15.000, df = 3, p = .002). The follow-up Wilcoxon Matched-Pair tests showed that they rated the combined higher than the template (z = -2.694, df = 3, and p = .007). They also rated the keyboard higher than the template (z = -2.536, df = 3, p = .011).

Table 18. Significant HMI Comparison Test Results of Ratings on ATC Communication in the Post-Scenario Questionnaire (D-side)

Tasks	**Friedman Test Results**		**Wilcoxon Test Results** **HMI Pairs**					
			K vs. C	**G vs. C**	**T vs. C**	**G vs. K**	**T vs. K**	**T vs. G**
Route modifications: Current	χ^2 = 9.256, p =.026, n = 12	z	-2.251 (n = 12)		-2.388 (n = 12)			
		p	.024		.017			
Crossing constraints at a specified altitude	χ^2 = -15.000, p = .002, n = 8	z			-2.694 (n = 9)		-2.536 (n = 9)	
		p			.007		.011	

Note. K = Keyboard; C = Combined; G = Graphical; T = Template.

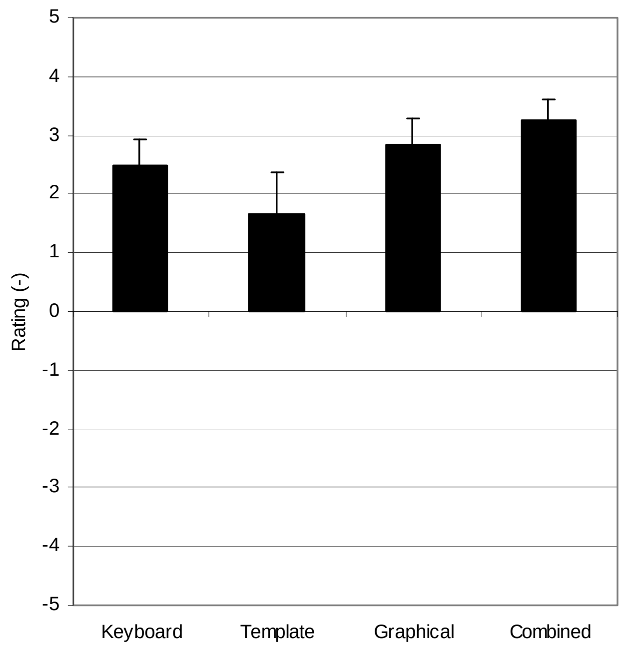


Figure 25. D-side controllers' average ratings on HMI modes for the task of current route modifications.

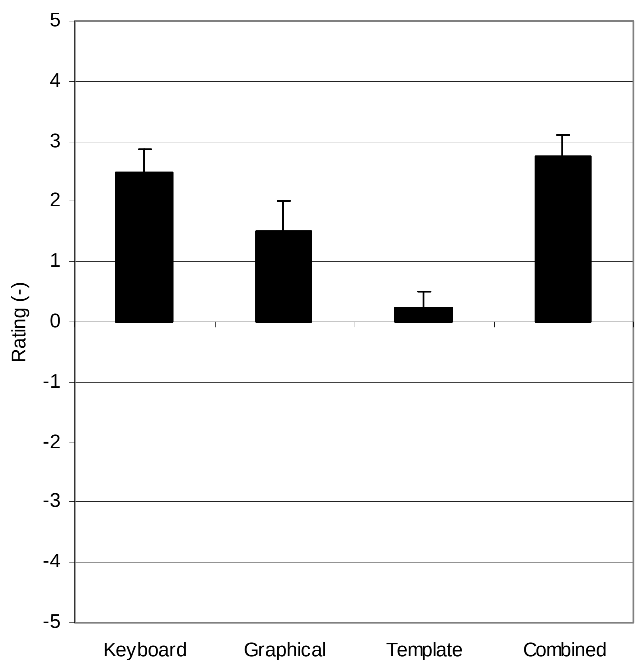


Figure 26. D-side controllers' average ratings on HMI modes for the task of crossing constraints at a specified altitude.

3.2.4 Exit Questionnaire

We asked controllers about their preference for using the template, keyboard, graphical, or combined interface as the sole input mode (see Appendix E). As we mentioned, we administered the Exit Questionnaire just after participant controllers finished the four HMI blocks of experimental runs. The results showed that both R- and D-side controllers regarded the template as the worst HMI design for Data Comm (see Table 19 and Figure 27).

Table 19. HMI Comparisons Test Using Ratings of the Exit Questionnaire (R-side and D-side)

Position	Friedman Test Results		Wilcoxon Test Results HMI Pairs					
			T vs. K	G vs. K	C vs. K	G vs. T	C vs. T	C vs. G
R-side	$\chi^2 = 26.045$, $p < .01$	*z*	-3.093			-3.077	-3.089	-2.324
		p	.002			.002	.002	.020
D-side	$\chi^2 = -28.368$, $p < .01$	*z*	-2.952		-2.223	-3.074	-3.075	-2.952
		p	.003		.026	.002	.002	.003

Note. For all χ^2 and rank tests, the *n* was 12. T = Template; K = Keyboard; G = Graphical; C = Combined.

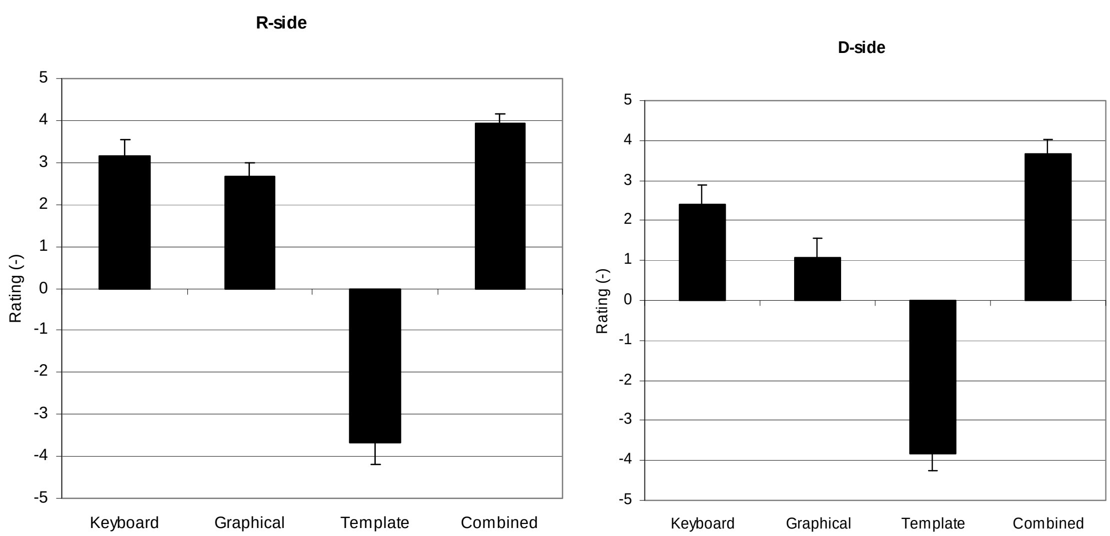


Figure 27. HMI ratings of the HMI Exit Questionnaire by R-side (left graph) and D-side (right graph).

The R-side controllers considered the combined mode was better than the Template and Graphical modes. They considered the template worse than other modes. The D-side controllers gave the similar ratings for Template. They also considered the Combined better than Graphical ($z = -2.952$, $p = .003$) and better than Keyboard ($z = -2.222$, $p = .026$).

3.2.5 Time and Distance (Efficiency)

The results of the repeated measure ANOVA analysis of the HMI modes did not show any significant results.

3.2.6 Functional Near Infrared Data

We analyzed the effect of HMI on changes in oxygenation and in general did not find a main effect of changes in HMI. The univariate results indicated an effect of controller position on oxygenation changes but that interacted only with the effect of HMI for Voxel 1, $F(3, 54) = 2.924$ at $p < .05$. Using the multivariate approach, the interaction did not reach significance.

We use Voxel 8 as an example of the effect of controller position and HMI on oxygenation because this effect was most visible for that voxel. Similar to what we found in the analysis of the effect of equipage level on oxygenation changes we found that the D-side controller had larger oxygenation changes than the R-side controller, $F(1, 18) = 13.501$ at $p < .01$ (see Figure 28). For Voxel 8, we did not find an interaction with the HMI variable, but the chart reflects the trend of our general findings. When the more advanced Data Comm capabilities were available only through keyboard entries, oxygenation increases were often smallest. The D-side had higher oxygenation changes than the R-side.

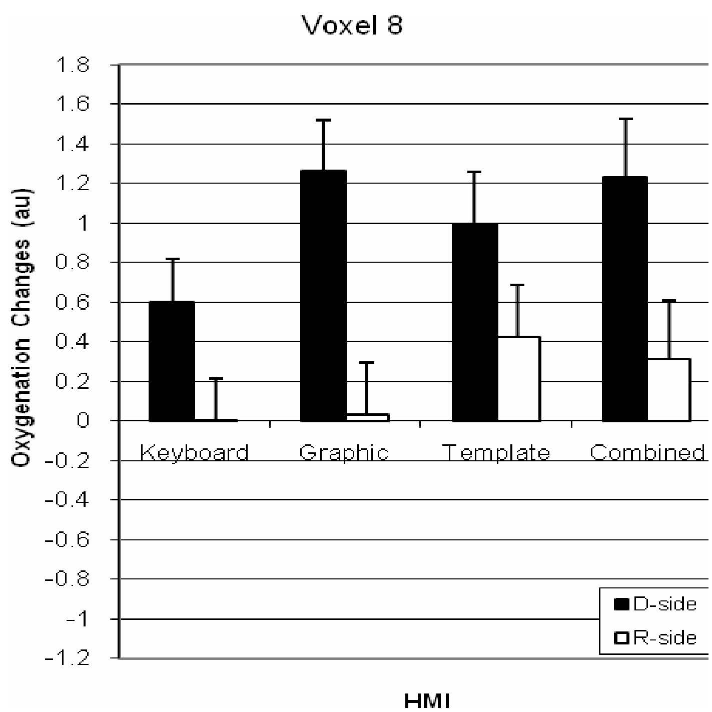


Figure 28. Voxel 8 as an example of the effects of controller position and HMI on oxygenation changes.

3.2.7 Aircraft Maneuvers

We wanted to know if the different human-machine interfaces affected the way the controllers issued clearances. We used repeated-measures ANOVA to evaluate the numbers of altitude, route and crossing clearances across the four HMI conditions.

Controllers gave significantly more altitude clearances when they used Data Comm than when they used voice communication, $F(1, 11) = 7.177, p < .05$. The effect of HMI was not statistically significant, nor was the interaction between communication mode and HMI.

There were no statistically significant differences in numbers of route clearances as a function of communication mode, HMI, or their interaction.

For crossing clearances, the interaction of communication mode and HMI was statistically significant, $F(3, 33) = 6.576, p < .05$. Figure 29 shows that when controllers used the Combined or Keyboard interface, they issued more clearances with Data Comm. When they used the Template interface, they issued fewer clearances with Data Comm than with voice communication. We used Tukey's HSD post hoc tests to compare means. The number of Data Comm crossing clearances issued using the Combined HMI was significantly greater than when using the Template, $q = 5.858, p < .05$; the number of crossings using the Keyboard was also greater than for the Template, $q = 4.632, p < .05$.

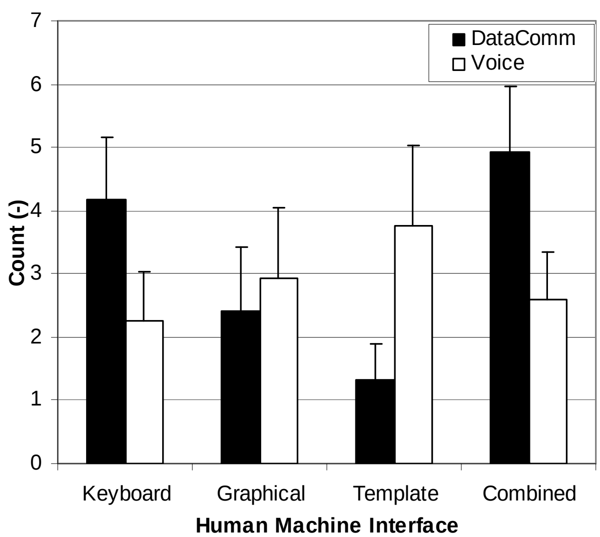


Figure 29. Crossing clearances by data and voice for four HMIs.

3.2.8 Controller Entries

Twelve teams comprised of one R- and D-side controller made 57,498 entries in four simulation scenarios (Keyboard, Graphical, Template, and Combined HMI conditions). Controllers aborted approximately 21% of all entries before updating the NAS or uplinking a message. Table 20 presents a breakdown by the types of data entries controllers made during the simulations.

Table 20. Number, Percentage, Mean, and Standard Deviation of Controller Entries Used During HMI Simulation Scenarios

			Duration (s)		
Entries	**Number**	**Percentage**	***M***	***SD***	**Results**
Aborted Controller Entries	11834	20.58%	0.801	2.538	NS
Toggle Suppression of Conflict Alert	4	0.01%	5.434	7.646	I
Modify the Situation Display Range Setting	23	0.04%	4.323	3.330	I
Modifying Vector Line Length	400	0.70%	3.048	3.643	NS
Dropping Area of Interest Data Block	2421	4.21%	0.455	1.539	S
Dropping Full Data Block	2741	4.77%	0.937	2.371	NS
Emphasis	223	0.39%	1.825	2.843	I
ERAM Button Clicked	180	0.31%	0.775	2.488	I
Error	2111	3.67%	2.348	3.748	S
Force Full Data Block	222	0.39%	1.544	4.879	I
Handoff Accept	4513	7.85%	0.855	2.373	S
Handoff Request	2833	4.93%	2.179	2.045	S
Continuous Range Readout	477	0.83%	2.833	2.119	I
Macro	2964	5.15%	3.100	4.097	S
Modify Route	1413	2.46%	4.369	3.507	NS
Offset Data Block	2	0.00%	7.944	0.914	I
Flight Plan Readout	10229	17.79%	1.736	2.039	NS
Lateral Offset	739	1.29%	1.147	2.380	S
Halo or Pointout	1187	2.06%	1.816	2.225	NS
Interim Altitude	1890	3.29%	4.000	3.124	NS
Heading	157	0.27%	4.115	2.849	NS
Speed	419	0.73%	5.176	3.893	NS
Display Probed Conflict Routes	185	0.32%	1.850	7.533	I
Assigned Altitude	1166	2.03%	4.227	3.112	NS
Set Velocity Vector Length	192	0.33%	0.188	0.159	I
Toggle Dwell Lock	340	0.59%	0.291	1.187	I
Toggle Forward Route	3951	6.87%	0.841	1.670	S
Toggle Limited Data Block	139	0.24%	0.197	0.232	I
Release Held Transfer of Communications	696	1.21%	1.216	3.289	I
Undefined	3816	6.64%	2.044	4.427	NS
Crossing Restriction	31	0.05%	12.716	9.210	I
Grand Total	*57498*	*100.00%*	*1.670*	*2.989*	

Note. NS = Statistical analysis did not yield significant results. I = The number of participants who made entries were too small to warrant statistical analysis; S = The detailed results contain each type of entry that yielded statistically significant results; ERAM = En Route Automation Modernization.

3.2.8.1 Display Routes

Our univariate analysis results indicated that changes in HMI conditions significantly altered the number of times controllers displayed routes, $F(3, 66) = 8.679$ at $p < .05$. When we followed up with a multivariate analysis, we found a significant interaction between the effects of controller interaction and HMI conditions, $\Lambda(3, 20) = .669$, $F(3, 20) = 3.305$ at $p < .05$. Because of the interaction, we analyzed simple effects and found that there was no significant difference between the number of routes displayed as a function of controller position within each of the HMI conditions. The effect of HMI condition on the number of routes display was significant within each of the controller positions, $F(3, 33) = 4.661$ and $F(3, 33) = 5.451$, for D- and R-sides, respectively, both at $p < .05$. Using the multivariate approach showed that the differences across HMI conditions did not reach statistical significance for the D-side, but it did for the R-side, $\Lambda(3, 9) = .256$, $F(3, 9) = 8.726$ at $p < .05$. A Tukey HSD post hoc revealed that the number of routes displayed was significantly different between the Keyboard and Graphical interface, between Template and Graphical interface, and between Combined and Template interface (see Figure 30). The participants displayed fewer routes under the Keyboard and Template HMI conditions. These differences only reached significance for the R-side controllers—even though a similar, but less pronounced, trend is visible for the D-side as well.

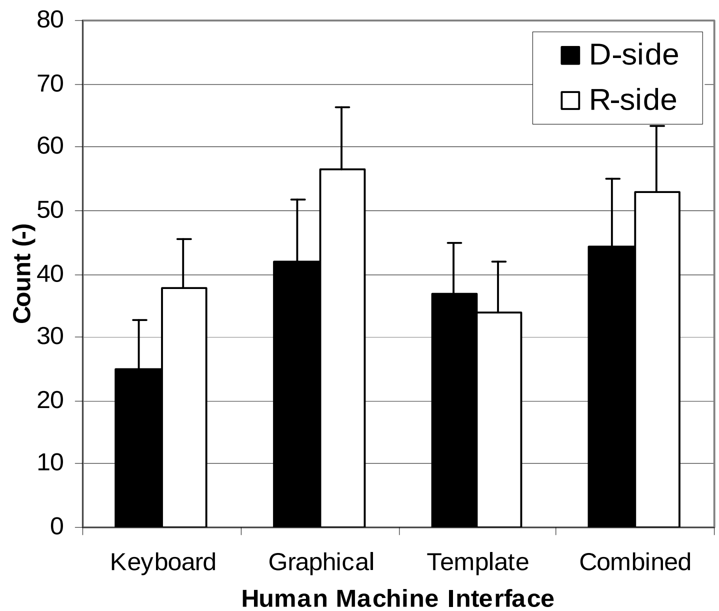


Figure 30. Number of route displays as a function of controller position and HMI options.

3.2.8.2 Dropping Area of Interest Data Blocks

We found that R-side controllers dropped Area of Interest Data Blocks (ADB) significantly more often than D-side controllers, $F(1, 21) = 4.529$ at $p < .05$. We did not find an interaction between the effect of HMI conditions and controller position.

3.2.8.3 Erroneous Entries

We found a significant main effect of controller position on the number of erroneous entries controllers made, $F(1, 22) = 6.360$ at $p < .05$. We also found a significant main effect of HMI conditions, $\Lambda(3, 20) = .669$, $F(3, 20) = 3.306$ at $p < .05$. R-side controllers made more erroneous entries than D-side controllers (see Figure 31). We had found a similar effect of controller position in the experimental design that investigated Equipage level, but here we found no interaction with the effect of HMI condition. A Tukey's HSD post hoc test on the effect of HMI revealed that none of the differences between conditions reached significance, although the difference between Combined and Template showed the largest difference (see Figure 32).

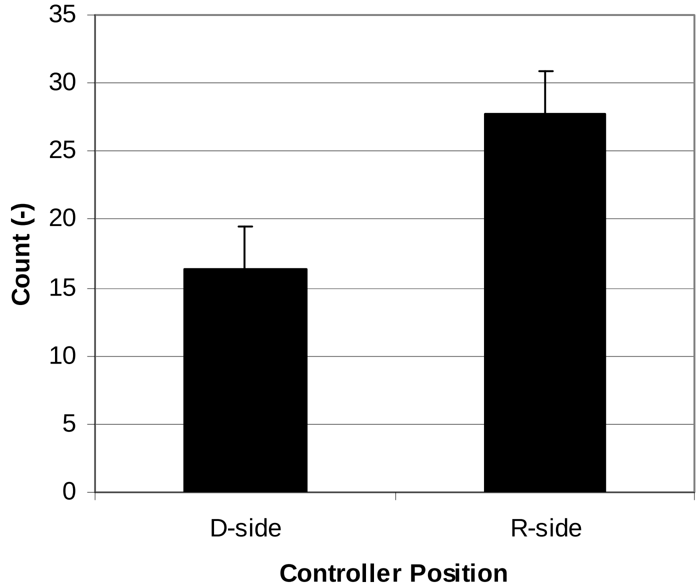


Figure 31. Number of erroneous entries as a function of controller position.

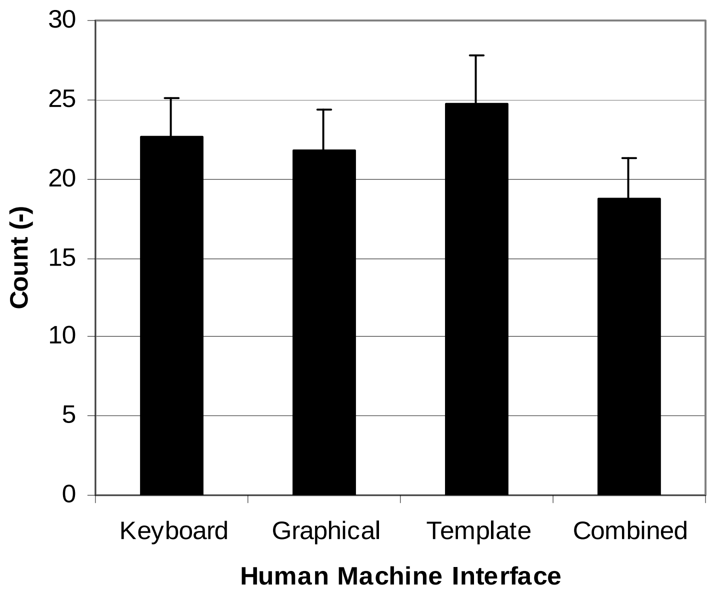


Figure 32. Number of erroneous entries as a function of HMI condition.

3.2.8.4 Handoff Accept

We found a significant interaction of the effects of controller position and HMI on the number of accepted handoffs, $F(3, 66) = 2.957$ at $p < .05$. Using the multivariate approach the interaction did not reach significance. Further breakdown by simple effects revealed that neither the effect of HMI within controller position nor the effect of controller position within each of the HMI conditions reached statistical significance. Although Figure 33 may seem to indicate that the D-side controllers took more handoffs under the keyboard and combined HMI conditions that R-side controllers, this difference did not reach statistical significance.

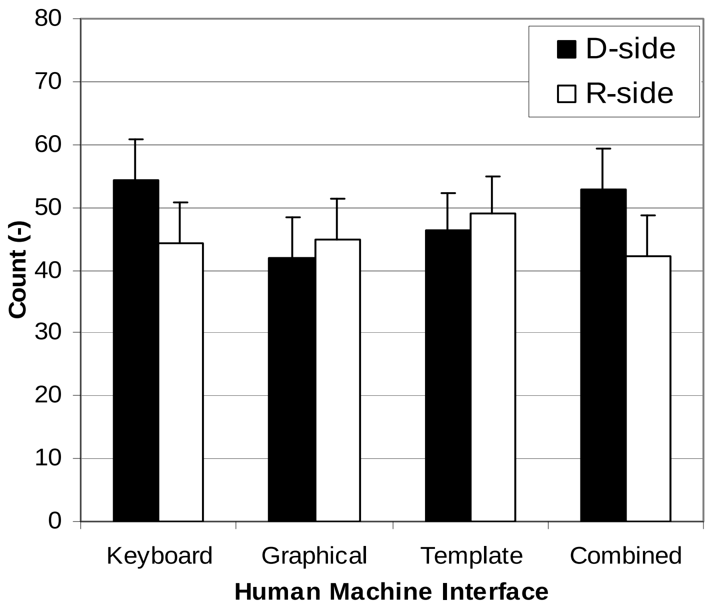


Figure 33. Number of handoffs accepted as a function of controller position and HMI condition.

3.2.8.5 Macros

We found a significant effect of HMI conditions on the number of macro entries controllers made, $F(3, 66) = 6.858$ at $p < .05$. The multivariate approach did not result in a significant difference. As shown in Figure 34, Tukey's HSD post hoc test analysis showed there was a difference between keyboard or combined conditions and graphical and template conditions.

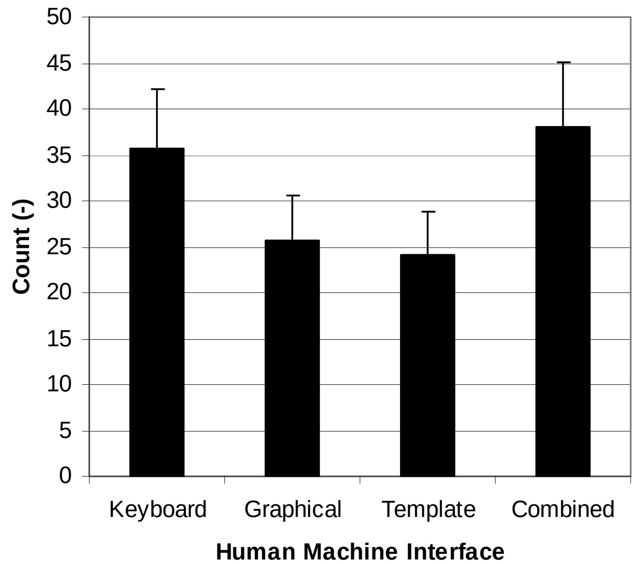


Figure 34. Number of macro entries as a function of HMI condition.

3.2.8.6 Flight Plan Readout

We found a significant effect of HMI on the number of flight plan readouts, $F(3, 66) = 3.834$ at $p < .05$. A Tukey HSD post hoc test revealed that controllers used fewer flight plan readouts under the graphical and combined HMI conditions. Figure 35 shows that R-side controllers made more flight plan readouts than D-side controllers, but that effect did not reach statistical significance.

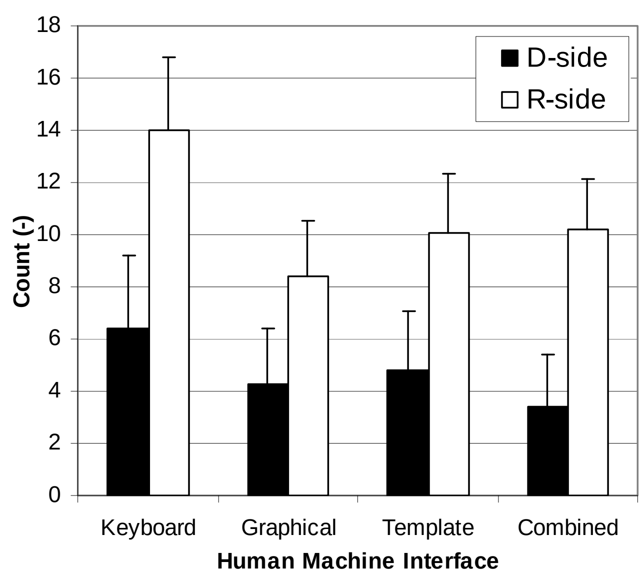


Figure 35. Number of flight plan readouts as a function of controller position and HMI.

3.2.9 Air Traffic Control Observer Ratings

For the HMI treatment, we ran a univariate ANOVA on each item, with the Bonferroni correction; no item showed significantly different ratings for any HMI.

3.2.10 Debriefing Comments

3.2.10.1 General

Two of the groups indicated that the views in general were taking up too much screen real estate and that they preferred integration of the data into the main display. Some groups provided reasons for keeping a view open which indicated that we could improve the integration. For example, one group mentioned that they kept the Message In View open because it was too easy to miss the downlink indicator in the Full Data Block (FDB).

Although we had implemented a Data Comm eligibility symbol that had a different shape than the position symbol, some controllers commented that they sometimes confused the two symbols. This may be a function of the amount of training controllers need before a symbol becomes an integral part of the aircraft object. Other controllers mentioned that the eligibility symbol could obscure the position symbol when they tucked a data block (reduced the leader line to zero length).

3.2.10.2 Keyboard

During the debriefing, the controllers indicated that they saw themselves as keyboard-oriented, and they wondered whether the younger generation of controllers is graphical user interface oriented. If the keyboard would be the only data entry method, controllers would like to see more dedicated function keys. We implemented the keyboard condition by providing all capabilities available in ERAM and by providing additional capabilities through a keyboard entry only. Because we considered macro entries as part of keyboard entries, controllers could still use them. Some of the controllers suggested that macros should be available if the keyboard is the only option for complex Data Comm entries.

3.2.10.3 Graphical

Five of the groups indicated that the graphical reroute capability helps a lot when rerouting aircraft that have Data Comm capabilities. Controllers could see a real benefit in rerouting aircraft around weather and special airspace using the graphical interface.

3.2.10.4 Template

Six of the seven groups found the template too cumbersome to use. Several of participants also indicated that they rarely use the templates available on URET for the same reason. Some of them suggest that it may be useful for the D-side when creating complex entries. For more routine entries, the template took too long to make entries. The participants suggested that it might be useful to have a template to build a complex macro. Complaints included taking longer to make an entry, blocking too much of the situation display, and distracting from the main visual scan.

3.3 Data Communication Equipage Level

3.3.1 Push-To-Talk

We conducted separate analyses on the number and the mean duration of PTT events as a function of equipage level. We found main effects of Actor and Equipage Level, $F(1, 22) = 56.53$ and $\Lambda(3, 20) = .003$; $F(3, 20) = 1721.256$, both at $p < .05$, respectively, and an interaction between Actor and Equipage Level, $\Lambda(3, 20) = .0351$, $F(3, 20) = 12.320$, $p < .05$. Because we found an interaction between Actor and Equipage Level, we conducted simple effect analyses. The repeated measures analysis showed a significant effect of Equipage Level on the number of controller PTT events, $\Lambda(3, 9) = .004$, $F(3, 4) = 700.821$, $p < .05$). A Tukey's HSD post hoc test revealed that the number of controller PTT events did not significantly differ between voice-only (0%) and 10% equipage, but it did differ significantly between 50% and 100% equipage levels. Our analysis of PTT event duration data did not reveal differences as a function of equipage level or actor.

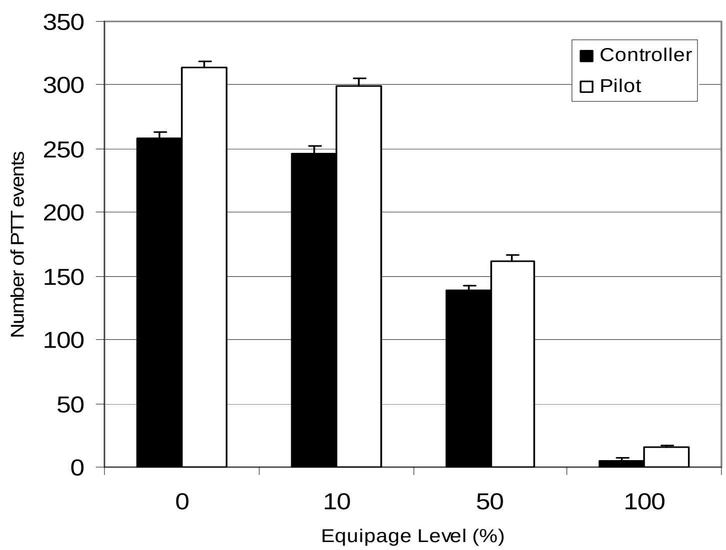


Figure 36. Number of PTT events as a function of equipage level.

3.3.2 Workload

Subjective workload ratings did not differ significantly between the Radar Controller and Data Controller. Pooled ratings for both positions showed a decrease in reported workload as equipage level increased. Tukey's HSD comparisons of means found workload in the 50% and 100% equipage condition to be significantly lower than for 0% (i.e., voice-only operation), $p < .005$ and $p < .001$, respectively. In addition, 100% equipage showed significantly lower workload than 10%, $p < .020$.

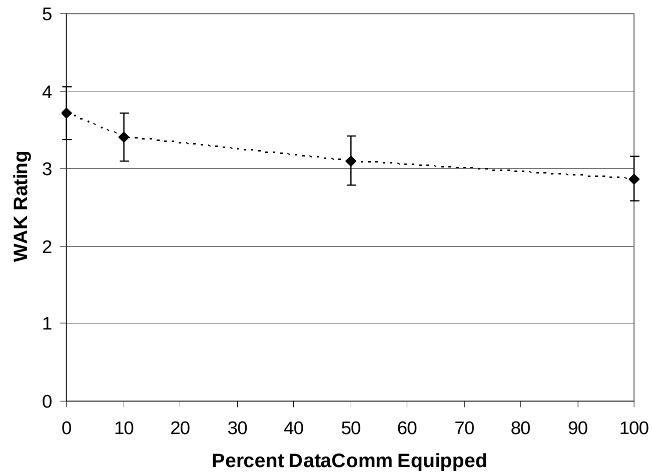


Figure 37. Subjective workload as a function of percentage of aircraft equipped for data communications.

3.3.3 Questionnaire

R-side controller ratings across the four equipage levels for all six ATC tasks were statistically different (see Table 21). For the task of situation monitoring, the difference between 100% and 0% was not significantly different, but the difference between 100% and 10% was significant. For the comparisons between 50% and 0% and the comparisons between 50% and 10%, those for the two tasks, Managing Aircraft Conflict, and Routing or Planning Flights, were significantly different.

Table 21. Significant Equipage Comparison Test Results of the Ratings on Six ATC Tasks for R-side Controllers

Tasks	**Friedman Test Results**	**Wilcoxon Test Results Equipage % Pairwise**						
			10 - 0	**50-0**	**100-0**	**50-10**	**100-10**	**100-50**
Situation monitoring	χ^2 = 12.190, p = .007	*z*					-2.384	
		P					.017	
Resolving aircraft conflicts	χ^2 = 8.922, p = .030	*z*			-2.319		-2.040	-2.214
		p			.020		.041	.027
Managing aircraft conflict	χ^2 = 16.929, p = .001	*z*		-2.342	-2.680	-1.992	-2.530	-2.124
		p		.019	.007	.046	.011	.034
Routing or planning flights	χ^2 = 17.337, p = .001	*z*		-.2671	-2.816	-2.201	-2.766	-2.156
		p		.008	.005	.028	.006	.031
Assessing weather impact	χ^2 = 9.955, p = .019	*z*			-2.375		-2.032	-1.843
		p			.018		.042	.065
Managing sector and position resources	χ^2 = 16.971, p = .001	*z*			-2.858		-2.808	-2.825
		p			.004		.005	.005

Note. For all χ^2 and rank tests, the *n* was 12.

The general pattern of the results showed that higher equipage levels helped controllers more in all of their tasks (see Figure 38). The 100% equipage level assisted controllers most in their tasks. The results showed there was no statistically significant difference between 0% and 10% in any of the six tasks.

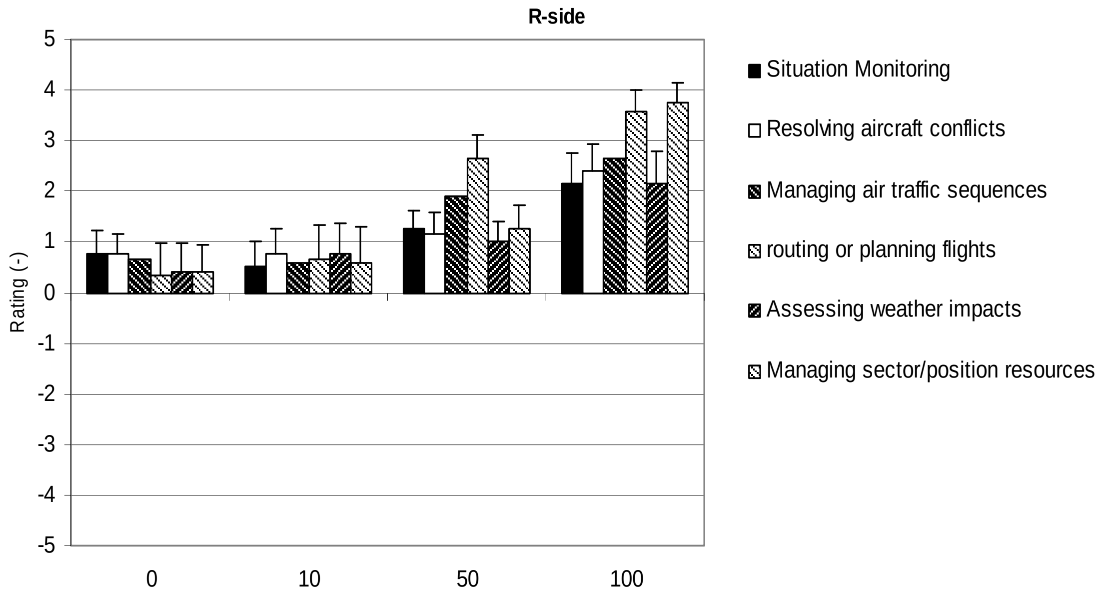


Figure 38. R-side controllers' average ratings on different equipage levels for ATC tasks.

For the D-side, only the questions on Routing or Planning Flights and on Managing Sector/ Position Resources showed significant Friedman test results (see Table 22). We present Wilcoxon Matched-Pair Rank test results below. The general pattern of the D-side results is similar to the R-side results (see Figure 39). The 100% equipage level was also the preferred equipage level for the D-side controllers.

Table 22. Significant Equipage Comparison Test Results of the Ratings on Six ATC Tasks for D-side Controllers

Tasks	**Friedman Test Results**	**Wilcoxon Test Results** **Equipage % Pairwise**						
			10 - 0	**50-0**	**100-0**	**50-10**	**100-10**	**100-50**
Routing or planning flights	$\chi^2 = 9.990$,	*z*			-2.639		-2.368	
	p = .019	*p*			.008		.018	
Managing sector and position resources	$\chi^2 = 9.084$,	*z*			-2.329		-2.103	-2.356
	p = .028	*p*			.020		.035	.018

Note. For all χ^2 and rank tests, the *n* was 12.

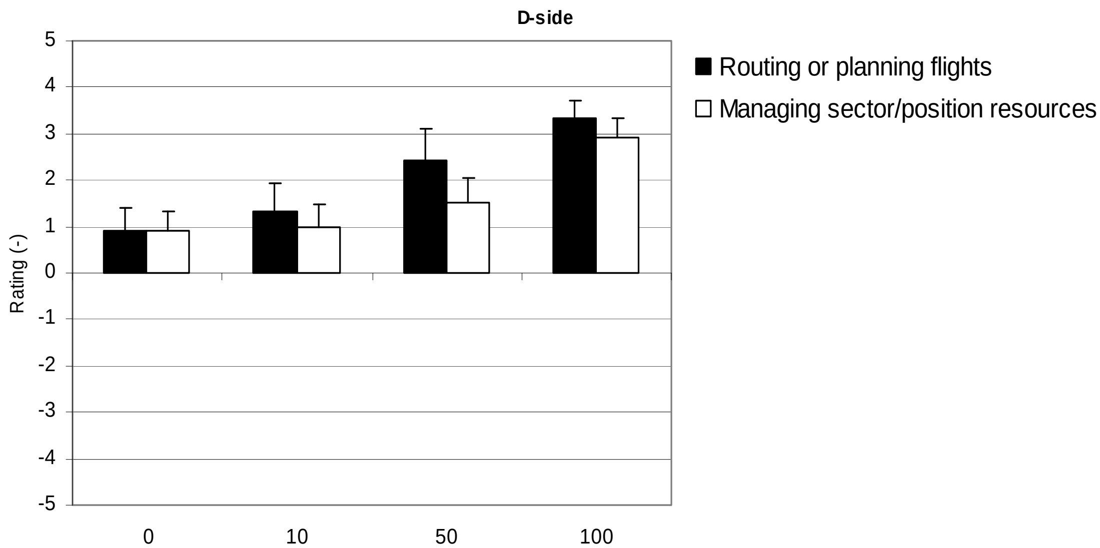


Figure 39. D-side controllers' average ratings on equipage levels for the tasks of routing or planning flights and managing sector/position resources.

The ratings of ATC tasks and ATC communication showed a similar pattern; that is, controllers preferred 100% equipage level (see Table 23). There was no clear advantage of 50% over 10%, overall, except the two tasks: Route Modifications-Current and Voice Frequency Assignment.

Table 23. Significant Equipage Comparison Test Results of the Ratings on ATC Communication for R-side Controllers

Tasks	**Friedman Test Results**	**Wilcoxon Test Results** **Equipage % Pairwise**						
			10 - 0	**50-0**	**100-0**	**50-10**	**100-10**	**100-50**
Instructions, advisories, and report requests	$\chi^2 = 7.971$, $n = 5$, $p = .047$	*z*			-2.070 ($n = 6$)		-2.060 ($n = 6$)	
		p			.038		.039	
Route modifications: Current	$\chi^2 = 13.645$, $n = 8$, $p = .003$	*z*		-2.226 ($n = 9$)	-2.536 ($n = 9$)	-2.106 (n = 10)	-2.527 ($n = 10$)	-2.754 ($n = 12$)
		p		.026	.011	.035	.012	.006
Vertical clearance: Current	$\chi^2 = 8.565$, $n = 8$, $p = .036$	*z*		-1.980 ($n = 9$)	-2.214 ($n = 9$)		-2.154 ($n = 9$)	
		p		.048	.027		.031	
Crossing constraints: Altitude	$\chi^2 = 12.070$, $n = 5$, $p = .007$	*z*		-2.214 ($n = 7$)	-2.410 ($n = 7$)		-2.264 ($n = 6$)	
		p		.027	.016		.024	
Voice frequency assignment	$\chi^2 = 14.020$, $n = 6$, $p = .003$	*z*		-2.366 ($n = 7$)	-2.375 ($n = 7$)	-2.371 (n = 10)	-2.384 ($n = 11$)	
		p		.018	.018	.018	.017	

The controllers rated that their voice frequency assignment tasks, such as instructing pilots to contact other sectors and monitoring frequencies of aircraft, were much easier when there were more aircraft with Data Comm capability than with verbal communication capability; 0% equipage level (see Figure 40). Especially, when 50% or 100% of the aircraft had Data Comm, the controllers rated that Data Comm helped them to perform the task in a very positive manner.

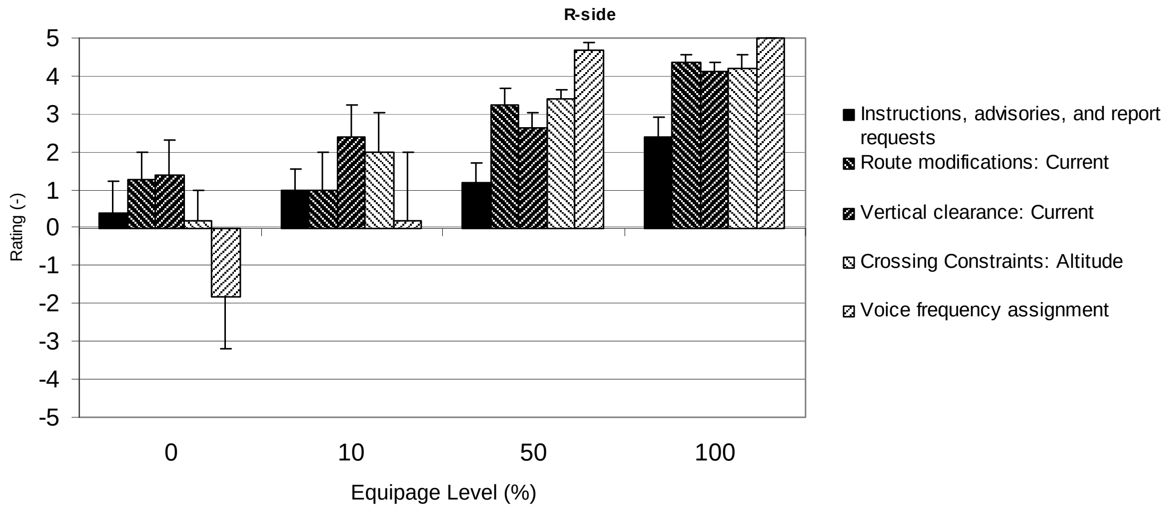
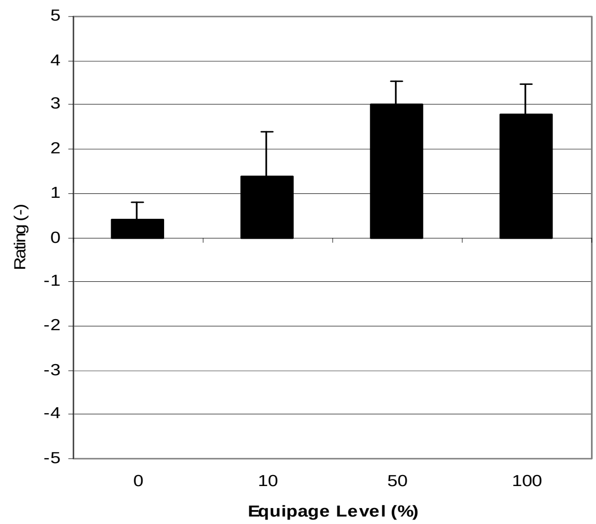


Figure 40. R-side controllers' average ratings on equipage levels for the air traffic communication tasks.

For the D-side controllers, *Crossing constraints: Altitude* was the only question that showed significant differences across the equipage levels ($\chi^2 = 8.659$, $p = .034$); see Table 24 and Figure 41. The number of data used for this testing was quite small (i.e., 5), because of many missing data; it lessens the significance of the result.

Table 24. Significant Equipage Comparison Test Results on ATC Communication for D-side Controllers

Tasks	Friedman Test Results	Wilcoxon Test Results Equipage % Pairwise						
			10 - 0	50-0	100-0	50-10	100-10	100-50
Crossing constraints: Altitude	$\chi^2 = 8.659$, $p = .034$ $n = 5$	*z*		-2.041 ($n = 5$)				
		p		.041				



Equipage Level (%)

Figure 41. D-side controllers' average ratings on equipage levels for the air traffic communication task of instructions, advisories, and report requests.

3.3.4 Aircraft Maneuvers

We wanted to know how the percentage of Data Comm-equipped aircraft in the airspace affected the type and number of clearances.

We analyzed the total numbers of cleared maneuvers for four levels of Data Comm equipage (see Table 25). We used the TGF data to tally actual numbers and percentages of aircraft with Data Comm in the airspace over the duration of the experimental run.

Table 25. Total Cleared Maneuvers by Data Comm Equipage

Nominal Equipage	0%	10%	50%	100%
Actual Equipage	0.0%	8.4%	51.5%	100.0%
Maneuvers	1518	1564	1580	1727

We used a one-way, repeated-measures ANOVA to analyze the twelve teams' individual totals. The Equipage effect was statistically significant, $F(3, 33) = 4.62$, $p < .01$. We used Tukey's HSD post hoc test to compare means. The difference between 0% and 100% Equipage conditions was statistically significant, $q = 4.979$, $p < 0.01$; also the difference between 10% and 100% Equipage, $q = 3.888$, $p < 0.05$. Therefore, Model 2, which predicts the total number of clearances to be the same across all equipage levels, is a poor fit for the data. Figure 42 shows counts of altitude, route and crossing clearances separately (Note: There were not enough speed or heading clearances for a meaningful analysis). Controllers issued noticeably more route clearances with higher equipage levels.

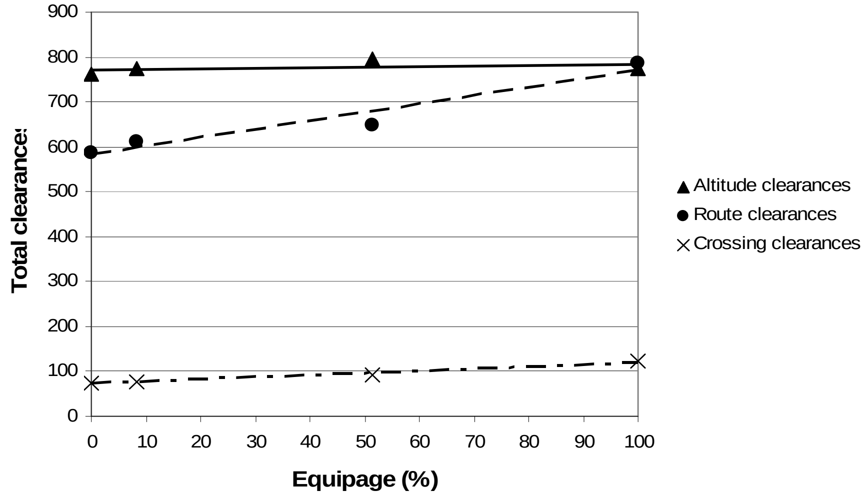


Figure 42. Altitude, route and crossing clearances in equipage runs.

For route clearances, a better fitting model includes a term proportional to the equipage factor; this is Model 3: Number of route clearances = (553 + 29 * V + 189 * Equipage fraction) * Equipage fraction, where $V = 0$ for clearances issued by data communication, and $V = 1$ for clearances issued by voice communication. This model agrees closely with the data (see Figure 43).

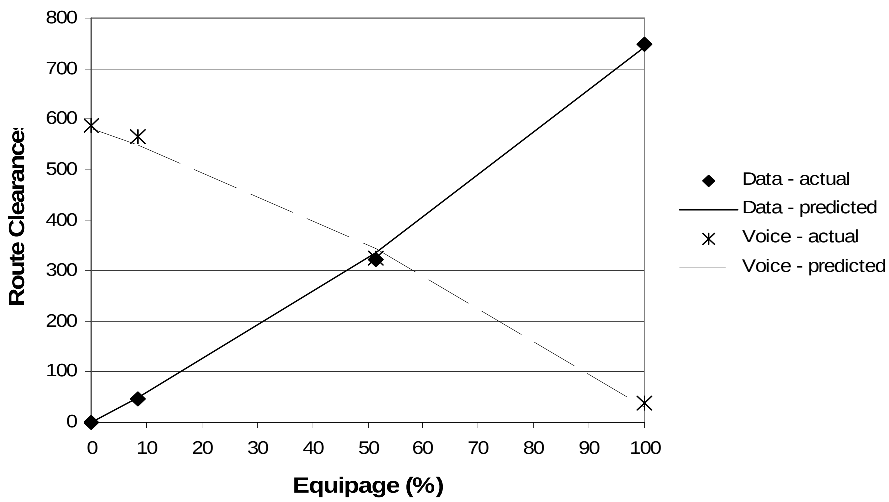


Figure 43. Voice and data route clearances by equipage level.

We looked at route clearances for two subgroups of flights, eastbound and westbound flights. Many westbound flights required re-routes around a large simulated convective weather system; we would expect that controllers issued these clearances in all conditions. Eastbound flights had clear air ahead of them, but some could be cleared to more direct routes to their destination airports, as controller workload permitted. Table 26 shows these selected counts of route clearances.

Table 26. Number of Maneuvers, Eastbound and Westbound Flights

		Data Comm Equipage			
Maneuver	Flight Direction	0%	10%	50%	100%
Route	Eastbound	260	275	296	395
Route	Westbound	196	190	203	221

We analyzed the means for the twelve teams using a two-way, repeated measures ANOVA. The effects of Flight Direction and Equipage were statistically significant, $F(1, 11) = 23.74$, $p < 0.05$, and $F(3, 33) = 11.21$, $p < 0.05$, respectively; their interaction was also significant, $F(3, 33) = 6.35$, $p < 0.05$.

We used the Tukey's HSD test to compare the particular clearances. The largest change is in route clearances for eastbound flights – many more were issued in the 100% Data Comm scenario. This scenario was significantly different from 0% Data Comm ($q = 9.957$, $p < .001$), 10% Data Comm ($q = 8.851$, $p < .001$) and 50% Data Comm ($q = 7.302$, $p < .001$). There were no significant differences in the number of re-routes for westbound flights across the different equipage levels.

3.3.5 Time and Distance (Efficiency)

The repeated measures ANOVA results of time and distance when aircraft were under the frequency showed a significant difference between equipage levels for both distance, $F(2.972, 1780.071) = 4.691$, $p = .003$, and duration, $F(2.977, 1783.018) = 4.144$, $p = .006$. The degrees of freedom were adjusted by Huynh-Feldt correction because both distance and duration variables violated the sphericity assumption of the covariance matrix of the orthogonalized transformation variables. The follow-up contrast results of distance showed that the difference between 100% and 0% (M = 4.7 nm, SE = 1.3 nm) and the difference between 100% and 10% (M = 4.0 nm, SE = 1.3 nm) were significantly different at $p = .002$ and $p = .011$, respectively (see Figure 44). The results of duration (see Figure 45) were similar to the difference between 100% and 0% (M = 38 s, SE = 11 s) and the difference between 100% and 10% (M = 32 s, SE = 11 s) were significantly different at $p = .005$ and $p = .023$, respectively.

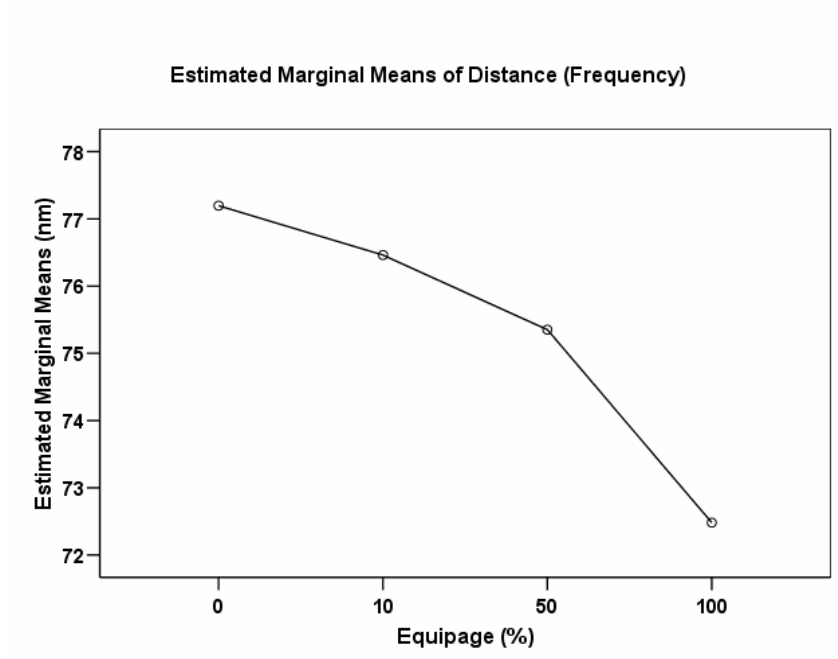


Figure 44. Estimated marginal means of distances on the frequency at different equipage levels.

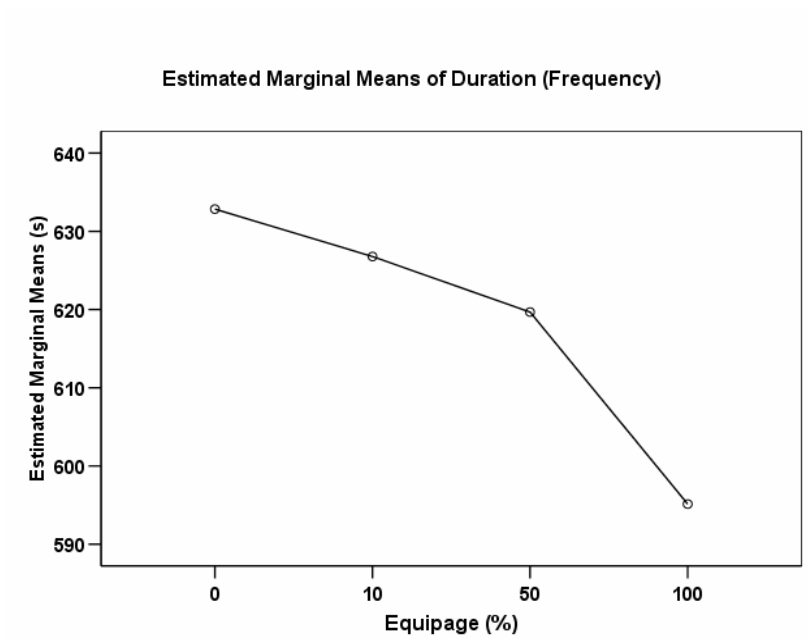


Figure 45. Estimated marginal means of durations on the frequency at different equipage levels.

The same analysis also showed significant results when aircraft were under the control of this (Sector 8), but the follow-up contrast tests did not any significant differences between equipage levels. The overall ANOVA test results were $F(3, 2085) = 2.745$, $p = .042$ for distance and $F(2.969, 2063) = 2.838$ with Huynh-Feldt correction of degrees of freedom.

For the other categories of control, geographical and responsibility, did not show significant results of the overall equipage levels.

3.3.6 Functional Near Infrared Data

The majority of the voxels, except 1, 3, 13, and 15, showed main effects of equipage on oxygenation levels (see Table 27) in the univariate approach to mixed design (position x equipage) ANOVA (Our preferred, multivariate, approach to repeated measures ANOVA loses power because we reduce the degrees of freedom from 54 to 16 and several of the analyses do not achieve significance at the .05 alpha level). We conducted repeated measures ANOVAs on the oxygenation levels of each of the 16 voxels. In general, we found a pattern of lower oxygenation levels for the voice-only condition that increased with 10% and that increased further with 50%, but dropped back down with 100% Data Comm equipped aircraft (see Figure 46).

Table 27. Multivariate and Univariate Results of Repeated Measures ANOVAs for Oxygenation Changes at Each Voxel

	Multivariate			Univariate	
Voxel	Wilks	$F(3, 16)$	p	$F(3, 54)$	p
1	.707	2.212	.126	2.226	.096
2	.609	3.422	.043	4.957	.004
3	.642	2.977	.063	2.532	.067
4	.528	4.760	.015	3.283	.028
5	.674	2.575	.090	3.258	.028
6	.494	5.467	.009	3.739	.016
7	.637	3.033	.060	3.944	.013
8	.679	2.519	.095	3.486	.022
9	.548	4.401	.019	4.766	.005
10	.713	2.148	.134	2.837	.047
11	.509	5.154	.011	4.922	.004
12	.420	7.352	.003	6.614	.001
13	.722	2.049	.148	2.480	.071
14	.692	2.372	.109	3.014	.038
15	.845	0.979	.427	0.516	.673
16	.534	4.662	.016	4.909	.004

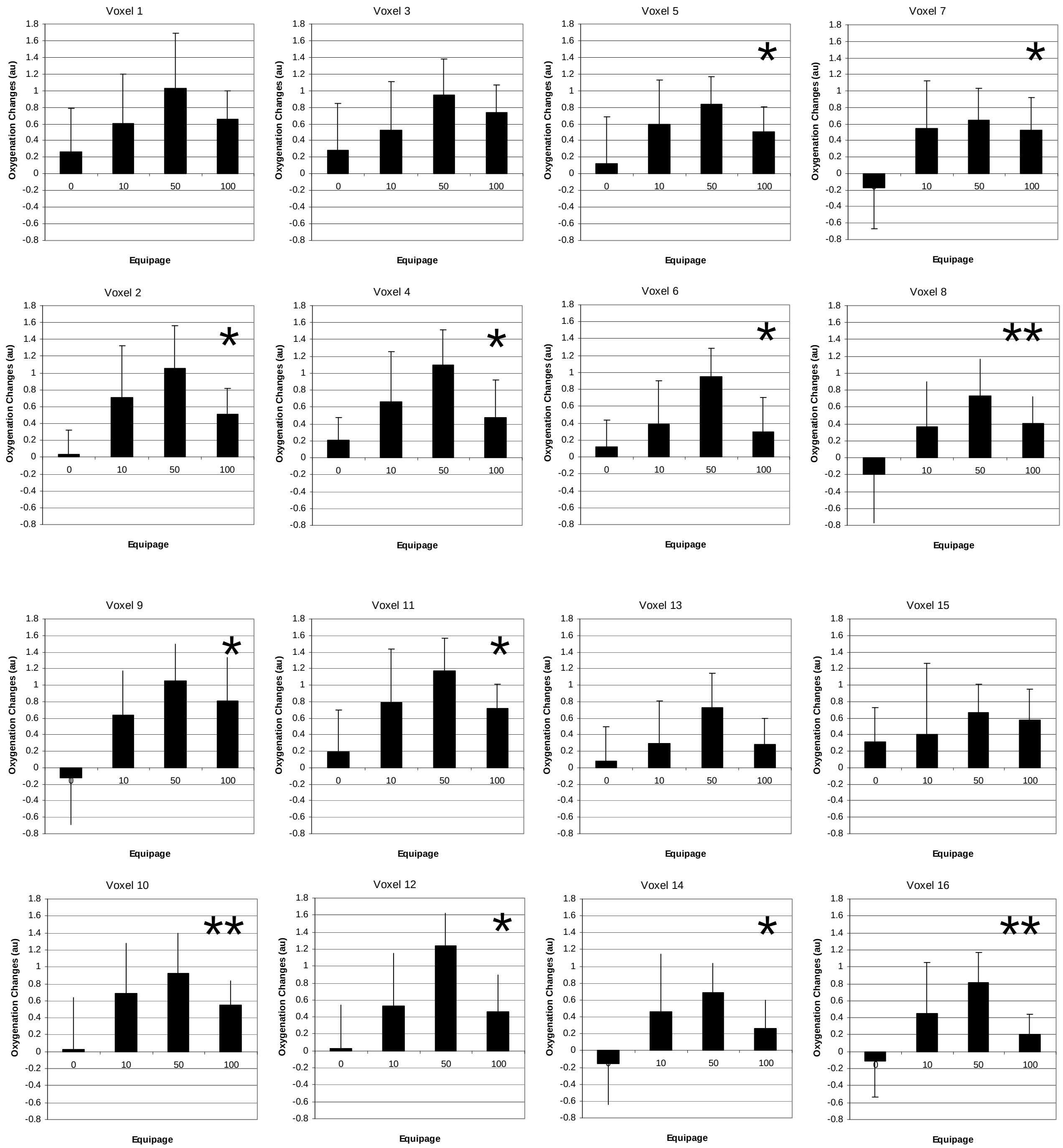


Figure 46. Oxygenation changes as a function of equipage level for each of the 16 voxels. An asterisk (*) indicates a significant main effect of equipage level and two asterisks (**) indicate that there also was a significant effect of controller position.

For three of the voxels we found an effect of controller position as well (see Figure 47). For Voxel 8 and Voxel 10 this was a main effect only, $F(1, 18) = 9.005$ and $F(1, 18) = 7.163$, respectively, both at $p < .05$. For Voxel 16 the effect of controller position was an interaction with equipage, $\Lambda(3, 16) = .522$, $F(3, 16) = 4.886$ at $p < .05$. The R-side controllers showed lower oxygenation levels than the D-side controllers for Voxel 8 and 10 (see Figure 47). We tested simple effects for the controller position by equipage effect at the Voxel 16 site and found that there was no effect of equipage on oxygenation change for R-side controllers. For D-side controllers, the oxygenation change at 50% equipage was significantly different from the voice-only and the 100% equipage conditions.

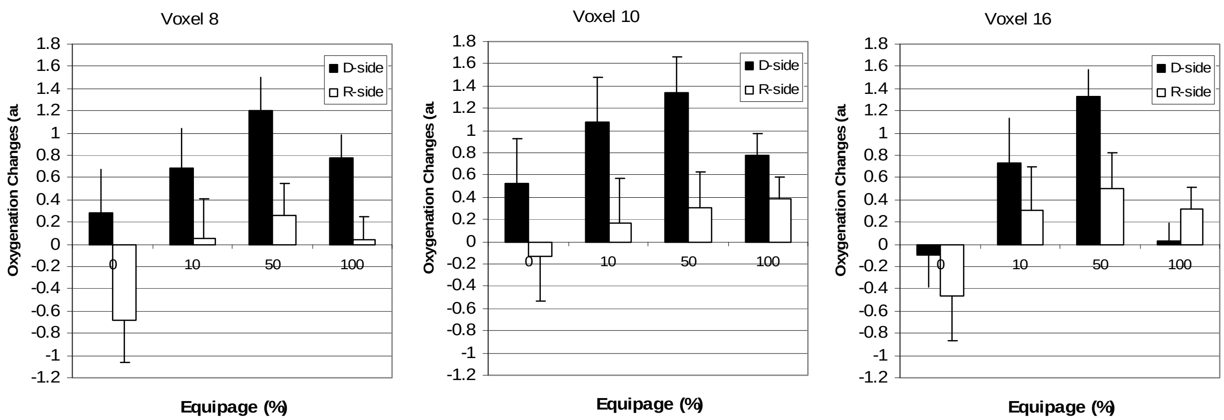


Figure 47. Effect of controller position and equipage on oxygenation change at Voxels 8, 10, and 16.

3.3.7 Controller Entries

Across 12 teams of R- and D-side controllers and four simulation scenarios (0%, 10%, 50%, and 100% equipage levels), controllers made 54,959 entries. Controllers aborted approximately 19% of all entries before updating the NAS or uplinking a message. In Table 28, we present a breakdown by the types of data entries controllers made during the simulations. To determine whether controllers changed their data entry behaviors, depending on the percentage of aircraft equipped with data communications and the position of the controller, we broke down the entries by position (R- and D-sides) and equipage level (0%, 10%, 50%, and 100%). In Table 28, we list the acronyms in the test results column as follows: S stands for Significant, I stands for Insufficient data, and NS stands for Non Significant.

Table 28. Number, Percentage, Mean, and Standard Deviation of Controller Entries Used During Equipage Simulation Scenarios

			Duration (s)		
Entries	**Number**	**Percentage**	***M***	***SD***	**Results**
Aborted Controller Entries	10,424	18.97%	0.890	2.299	S
Toggle Suppression of Conflict Alert	7	0.01%	3.271	6.073	I
Modify the Situation Display Range Setting	21	0.04%	4.486	4.691	I
Modifying Vector Line Length	359	0.65%	2.682	2.739	I
Dropping Area of Interest Data Blocks	2,290	4.17%	0.452	1.150	S
Dropping Full Data Blocks	2,403	4.37%	0.972	2.640	S
Emphasis	233	0.42%	1.730	3.099	I
ERAM Button Clicked	125	0.23%	0.448	1.497	I
Error	1,797	3.27%	2.389	3.645	S
Force Full Data Block	333	0.61%	1.643	4.040	I
Handoff Accept	4,649	8.46%	0.800	2.123	S
Handoff Request	2,872	5.23%	2.243	2.414	S
Continuous Range Readout	484	0.88%	2.688	1.883	I
Macro	3,170	5.77%	3.190	4.377	S
Modify Route	1,550	2.82%	4.286	3.683	I
Offset Data Block	10,321	18.78%	1.774	2.094	S
Flight Plan Readout	607	1.10%	1.137	1.893	NS
Lateral Offset	2	0.00%	8.000	2.404	I
Halo or Pointout	1,555	2.83%	2.049	2.957	NS
Interim Altitude	2,053	3.74%	3.502	2.941	S
Heading	137	0.25%	4.944	3.292	NS
Speed	439	0.80%	4.581	3.174	S
Display Probed Conflict Routes	126	0.23%	2.534	10.195	I
Assigned Altitude	1,011	1.84%	3.972	2.836	S
Set Velocity Vector Length	152	0.28%	0.236	0.775	I
Toggle Dwell Lock	157	0.29%	0.231	0.829	I
Toggle Forward Route	4,214	7.67%	0.761	1.242	I
Toggle Limited Data Block	75	0.14%	0.163	0.077	S
Release Held Transfer of Communications	479	0.87%	1.177	3.041	I
Undefined	2,895	5.27%	1.818	3.753	S
Crossing Restriction	19	0.03%	6.932	6.997	I
Grand Total	*54,959*	*100.00%*	*1.690*	*2.856*	

Note. S = Significant. The detailed results contain each type of entry that yielded statistically significant results; I = Insufficient Data. The number of participants who made entries were too small to warrant statistical analysis; NS = Non Significant. Statistical analysis did not yield significant results.

3.3.7.1 Aborted Controller Entries

Controllers can abort their entries in a number of different ways. When making keyboard entries, controllers have a dedicated CLEAR key that empties the Message Composition Area (MCA). Controllers frequently use this to ensure that partial entries are present in the MCA that could result in a format-related rejection of their entry by the system. Alternatively, controllers can use one of the dedicated function keys. Use of these keys first empties the MCA before entering the beginning of the appropriate controller entry. When controllers make an entry using FOMs, they can abort an entry by clicking on an "x" in the top right corner of the FOM, by clicking in empty space on the map of the situation display, or by using the CLEAR key. When using the interactive trajectory to create entries, controllers can remove the trajectory display to abort an entry. When using the clearance template, controllers simply close the template to abort an entry.

We conducted a 2 x 3 (Position x Equipage) repeated measures ANOVA on the number of aborted entries. We found a main effect of Equipage on the number of aborted entries, $F(3, 66) = 3.16$, $p < .05$ (see Figure 48.). The effect of Position and the interaction between Position and Equipage did not reach statistical significance. Because the Equipage variable has more than two levels we performed a Tukey's HSD post hoc test to determine which differences between equipage levels were statistically significant. We found that the number of aborted entries under the100% equipage condition was significantly lower than the number of aborted entries under the 0% (voice-only) condition. Although there seems to be a reduction in aborted entries with an increase in equipage levels, the differences between other equipage level pairs did not reach statistical significance.

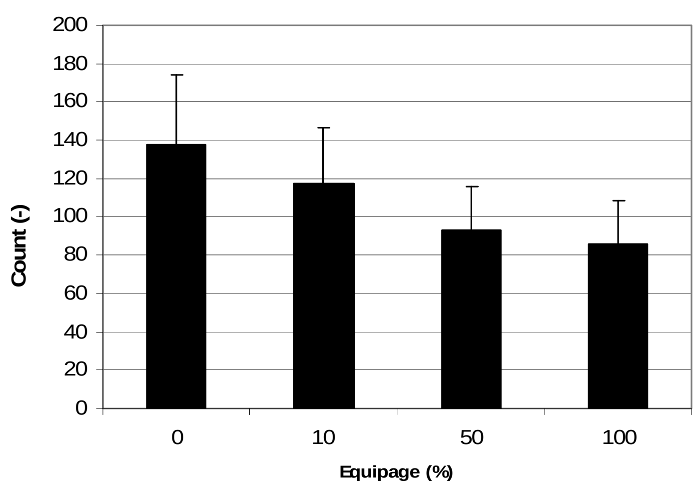


Figure 48. Number of aborted controller entries as a function of equipage level.

3.3.7.2 Dropping Area of Interest Data Blocks

The initial version of ERAM introduced a cycle of data blocks that dropped an FDB to an Area of interest Data Block (ADB); this was only possible for an aircraft not under control of the current sector and an ADB to a correlated Limited Data Block (LDB). Our analysis of the number of times controllers dropped ADBs further to a correlated LDB showed a statistically significant interaction between the effects of controller position and equipage level, $\Lambda(3, 20) = .635$, $F(3, 20) = 3.824$, $p < .05$ (see Figure 49). We further investigated the simple effects of controller position within each level of equipage and the effect of equipage with each controller position, but we did not find statistically significant effects even though Figure 49 shows that the R-side controllers drop the data blocks from an ADB to a correlated LDB more often than the D-side controllers.

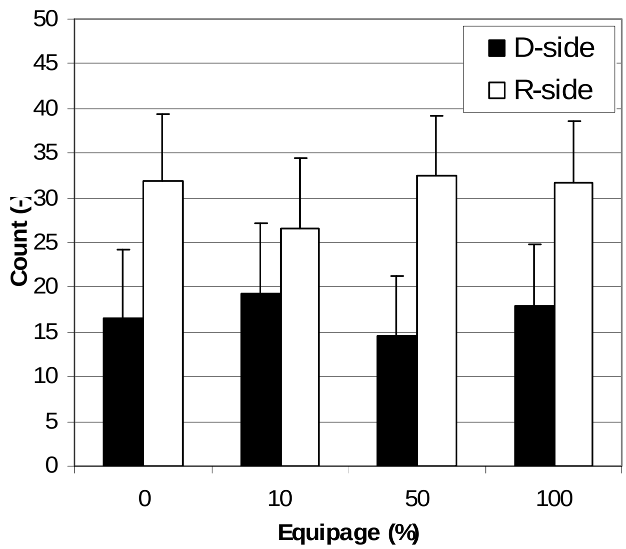


Figure 49. Number of entries to drop ADBs as a function of controller position and equipage level.

When analyzing the data, we found that several controller teams did not seem to drop any ADBs (see Table 29). Controllers try to reduce clutter on their display, as much as possible, by not removing data blocks after aircraft have left the sector seems counterintuitive. We further investigated how controllers may have been able to remove data blocks from their display without making the expected entries.

Table 29. Counts and Mean Duration (s) of Controller Entries to Drop ADBs as a Function of Controller Position and Equipage Level

		0%		10%		50%		100%	
Position	**Team**	**Count**	**Duration**	**Count**	**Duration**	**Count**	**Duration**	**Count**	**Duration**
D-side	03	55	0.300	67	0.381	50	0.380	47	0.634
D-side	04	9	0.633	12	0.383	4	0.475	20	0.545
D-side	05	2	0.350	4	0.325	0		0	
D-side	06	6	0.783	13	0.200	12	0.483	23	0.183
D-side	07	3	0.133	3	0.133	3	0.100	9	0.144
D-side	08	0		1	0.100	1	0.100	0	
D-side	09	49	0.565	52	0.279	46	0.502	41	0.254
D-side	10	10	0.440	6	0.717	0		11	0.527
D-side	11	63	0.210	71	0.161	56	0.155	62	0.258
D-side	12	1	0.200	2	0.250	2	0.200	2	0.200
D-side	13	0		0		0		0	
D-side	14	1	0.900	0		0		0	
R-side	03	19	0.221	8	0.200	24	0.437	27	0.385
R-side	04	65	0.488	50	0.440	63	0.886	53	0.711
R-side	05	11	0.373	6	0.417	16	0.444	25	0.404
R-side	06	15	1.313	20	0.300	44	0.443	8	0.275
R-side	07	0		2	0.100	2	0.200	5	0.140
R-side	08	15	0.380	5	0.260	3	0.167	10	0.190
R-side	09	30	0.573	29	0.431	35	0.466	40	0.357
R-side	10	64	0.964	66	0.921	52	0.612	54	0.424
R-side	11	16	0.138	4	0.200	19	0.142	14	0.129
R-side	12	72	0.890	71	0.699	56	0.430	72	0.378
R-side	13	0		0		3	0.667	2	0.100
R-side	14	75	0.479	58	0.257	72	0.368	71	0.172

We looked at entries made by Team 13 for an aircraft that the sector team had accepted (see Table 30). The R-side controller accepted the handoff for UPS3015 at approximate 20:15 minutes into the simulation through a keyboard entry of the Computer Identification (CID). The R-side controller moved the FDB to the North position (i.e., the 2-position on the numeric keypad) at approximately 20:16 minutes into the simulation. The controller then pointed the aircraft to his or her own sector by using the PVD key (entering a QP command). This action hid the data block from the display without the need to cycle through the ADB.

Table 30. Example of a QP Entry to Drop an Full Data Block to a Correlated Limited Data Block Without Going Through an Area of Interest Data Block Format First

Position	Team	Equipage	Start Time	End Time	Call Sign	Task	Source	Method	Comm	Entry Content
R-side	13	000	00:20:14.333	00:20:15.103	UPS3015	Handoff Accept	CRD	keypress	NAS	618
R-side	13	000	00:20:15.666	00:20:16.267	UPS3015	LeaderChangeRequest	CRD	keypress	NAS	2 618
R-side	13	000	00:33:18.189	00:33:24.070	UPS3015	QP	CRD	keypress	NAS	QP 618

Note. CRD = Computer Readout Device.

3.3.7.3 Dropping Full Data Blocks

To reduce clutter on the situation display, controllers drop data blocks when aircraft have physically left the sector and no further action on the aircraft is necessary. The univariate results of our analysis showed a trend in the effect of controller position, but it did not reach statistical significance even though data suggests that the R-side controller seems to drop the data blocks from the display more often than the D-side controller (see Figure 50).

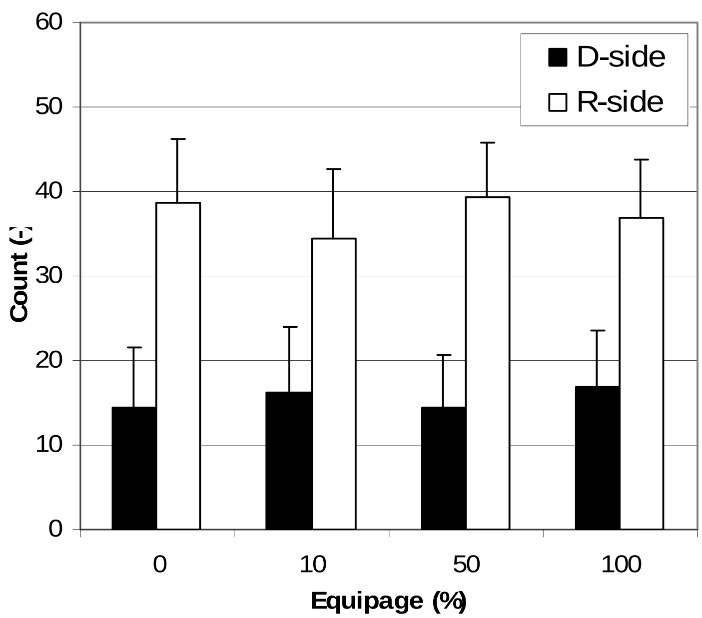


Figure 50. Number of entries to drop FDBs as a function of controller position and equipage level.

3.3.7.4 Error Message

Our simulation platform recorded each controller entry that resulted in an error message; for example, the entry was either in the wrong format for a controller command or contained a reference to a nonexisting aircraft. We analyzed the number of times controllers made erroneous entries and found a significant interaction between controller position and equipage level, $\lambda(3, 20) = .646$, $F(3, 20) = 3.655$, $p < .05$ (see Figure 51). Because of the significant interaction, we analyzed the simple effects of equipage within each of the positions and of position within each of the equipage level. We found that there was no significant effect of equipage on the number of errors that the D-side controllers made. There was, however, a significant effect of equipage on the number of errors that the R-side controller made. The univariate approach to repeated measures analysis resulted in a significant effect, $F(3, 33) = 4.077$, $p < .05$. The multivariate approach to repeated measures analysis did not reach statistical significance. A Tukey's HSD post hoc test revealed that the R-side controllers made significantly fewer erroneous entries under the 100% equipped condition, but that difference only reached significance between the 10% and the 100% conditions; *t*-tests within each of the equipage levels showed that the difference between the R-side and D-side within the 0% condition was not statistically significant. The R-side had significantly more errors in the 10% equipage condition, $t(22) = -2.236$, $p < .05$ and in the 50% condition, $t(22) = -2.195$, $p < .05$. There was no significant difference in the number of errors under the 100% equipage condition.

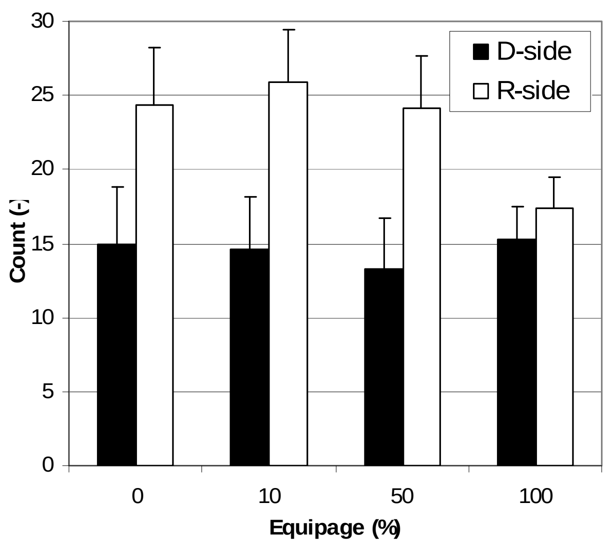


Figure 51. Controller entry errors as a function of controller position and equipage level.

3.3.7.5 Handoff Request

We recorded the number of times controllers manually handed aircraft off to the next sector. Unless an aircraft is on Flight Plan Assisted Tracking (FLAT), controllers will manually handoff aircraft to the next sector. We found that equipage level affected the number of aircraft that controllers manually handed off, $F(3, 66) = 2.92$, $p < .05$ (see Figure 53). Although Figure 53 shows that there is a reduction in the number of manual handoffs as equipage level increases, the post hoc analysis did not reveal significant results.

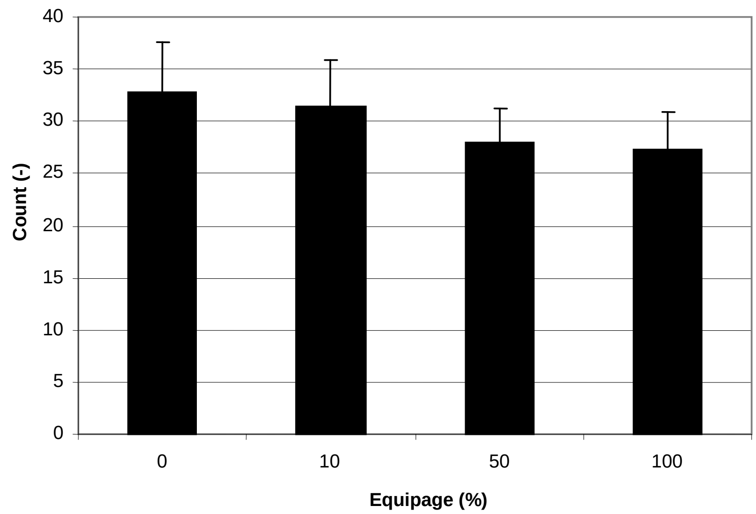


Figure 52. Number of manual handoffs as a function of equipage level.

3.3.7.6 Macros

We recorded the number of times controllers used macros to make entries into the system and/or uplink messages to aircraft. Controllers use this feature quite frequently. We conducted a 2 x 3 (Position x Equipage) repeated measures ANOVA on the number of macro entries to determine if macro usage between the R- and D-side controllers changed as a function of equipage level. We found a main effect of equipage, $F(3, 66) = 26.38$, $p < .05$ (see Figure 53). The effect of Position and the interaction between Position and Equipage did not reach statistical significance. Because the Equipage variable has more than two levels we performed a Tukey's HSD post hoc test to determine which differences between equipage levels were statistically significant. We found that the number of macro entries was not significantly different between the voice-only and the 10% equipage conditions, but significant between all other pairs.

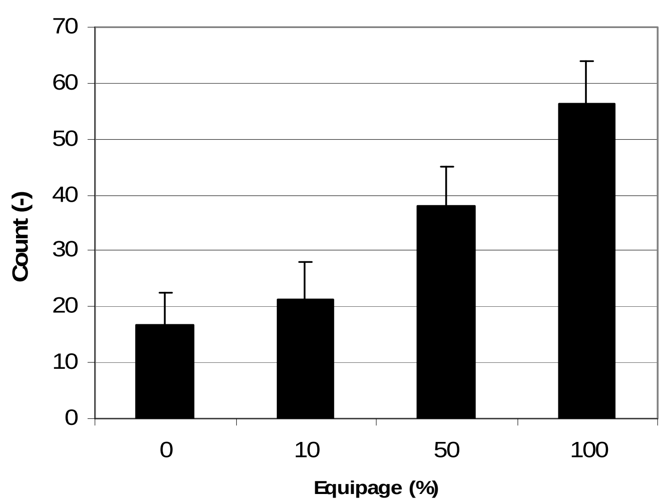


Figure 53. Number of macro entries as a function of equipage.

3.3.7.7 Offset Data Block

We found a significant change in the number of times controllers moved data blocks, $\Lambda(3, 20) = .626$, $F(3, 66) = 5.438$, $p < .05$. A Tukey's HSD post hoc test revealed that controllers moved significantly less data blocks in the 100% than in the 0% and 10% conditions, but there was no difference between the 0% and 10% or the 50% and 100% equipage conditions (see Figure 54).

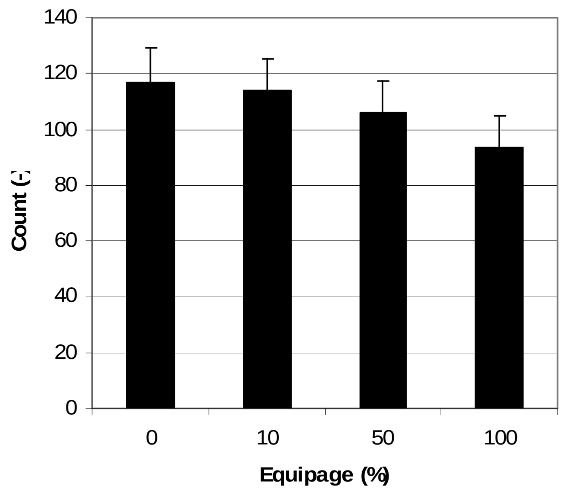


Figure 54. Number of data block offsets as a function of equipage.

3.3.7.8 Interim Altitudes

We found a significant difference in the number of interim altitudes the controllers used as a function of equipage level, $F(3, 66) = 8.083$, $p < .05$ (see Figure 55). A Tukey's HSD post hoc test revealed that with 100% aircraft equipped, controllers used a significantly lower number of interim altitude entries than with either 0% or 10% equipage levels. With 50% of the aircraft equipped, controllers used significantly fewer interim altitude entries than when no aircraft had data communications capabilities, but the difference between 50% and 10% equipage levels did not reach significance.

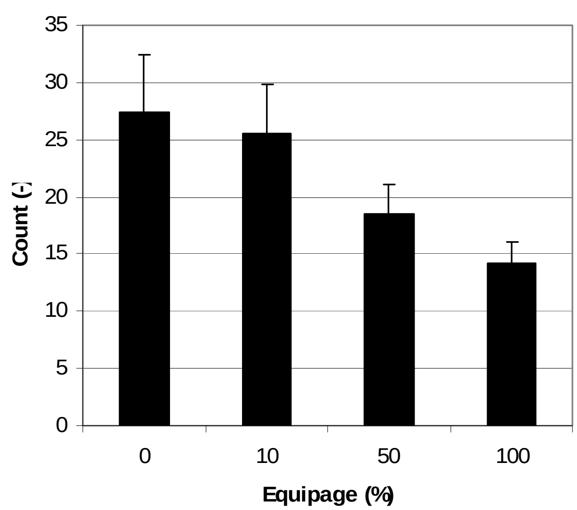


Figure 55. Number of interim altitudes as a function of equipage.

3.3.7.9 Speed entries

Controllers did not make frequent speed entries into the fourth line of the data block, but we analyzed the number of entries to see if controller position or equipage level affected the number of entries. We found a significant interaction between the effects of controller position and equipage level using the univariate approach to repeated measures analysis, $F(3, 66) = 3.487$, $p < .05$ (see Figure 56), but the multivariate analysis did not show significant results. To further investigate the interaction we conducted simple effects analysis of equipage level within controller position and of controller position within equipage level. We found that the effect of equipage level within the R-side position was not significant. The effect of equipage level with the D-side position was significant, $F(3, 33) = -3.585$, $p < .05$. A Tukey HSD post hoc test revealed that the D-side controller made significantly more speed entries during the 100% equipage conditions than during the 50% conditions, but none of the other pairs differed significantly. Although the difference between R- and D-side controllers suggests that the D-side controllers made more speed entries than the R-side controllers, *t*-tests revealed that only under the 100% equipage conditions the D-side made significantly more speed entries than the R-side controller, $t(22) = 2.095$, $p < .05$.

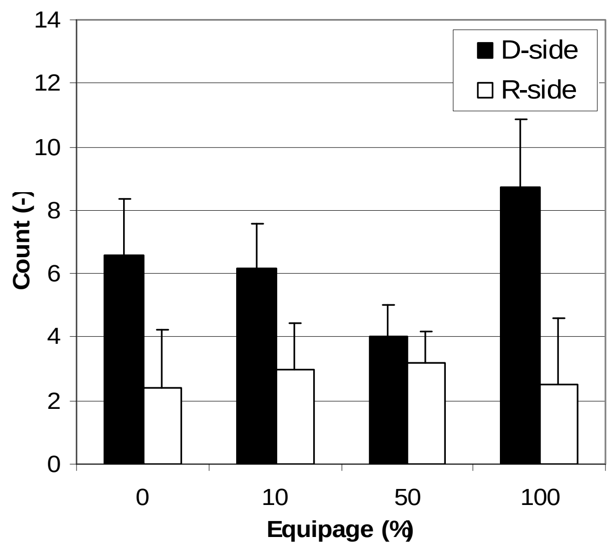


Figure 56. Number of Speed entries as a function of controller position and equipage.

3.3.7.10 Assigned Altitudes

The traffic scenarios used in this experiment had aircraft descending into several airports as well as aircraft climbing to cruise altitude. We analyzed how often controllers indicated that they had modified the assigned altitude and found a significant effect of equipage level, $\Lambda(3, 20) = .491$, $F(3, 20) = 6.908$, $p < .05$ (see Figure 57). A Tukey HSD post hoc test revealed that the number of assigned altitude entries under 50% equipage conditions was significantly different from the 0% and 10% equipage conditions and that the number of entries under 100% equipage conditions was only different from the 0% equipage condition.

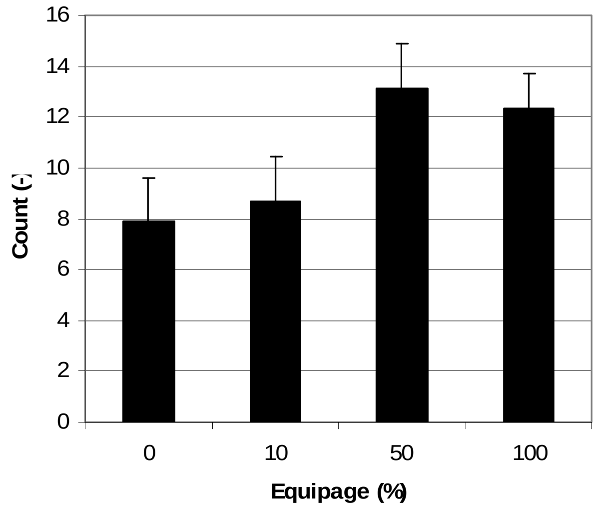


Figure 57. Number of assigned altitude changes as a function of equipage level.

3.3.7.11 Toggle Forward Route

Controllers had the option to display the interactive route through the keyboard—as is currently possible in the Display System Replacement (DSR) and ERAM systems—or through an interaction with the FDB by clicking on the destination field. We analyzed the number of times controllers toggled the forward route display and found that equipage level had a significant effect on how often controllers used this feature, $\Lambda(3, 20) = .611$, $F(3, 20) = 4.238$, $p < .05$ (see Figure 58). A Tukey's HSD post hoc test revealed that controllers displayed routes significantly more frequently when working traffic with 50% or 100% equipage than with 0% or 10% equipage.

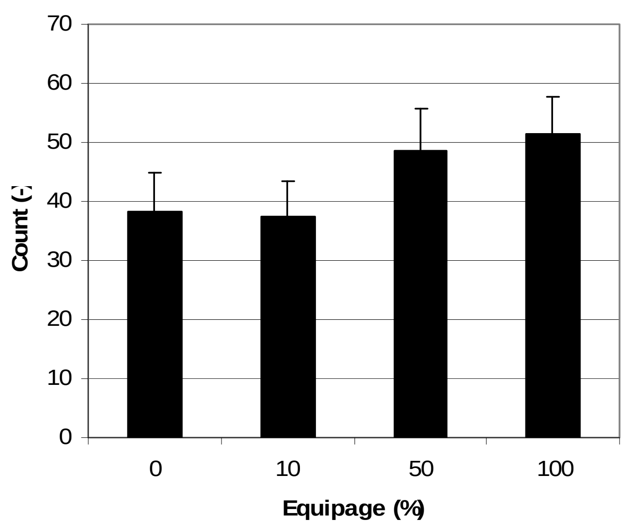


Figure 58. Number of Forward Route Toggle entries as a function of equipage.

3.3.7.12 Undefined entries

We recorded a number of entries that were grammatically correct, but did not result in an update of the system. Examples of these types of interactions are a click on a position symbol that only results in a handoff acceptance or a change in data block type under certain conditions, but does not result in a system update under other conditions. Our analysis showed that there was a significant increase in the number of undefined entries, $\Lambda(3, 20) = .458$, $F(3, 20) = 7.887$, $p < .05$ (see Figure 59). A Tukey's HSD post hoc test revealed that the number of undefined entries under 50% and 100% equipage levels was higher than under 0% and 10% equipage levels.

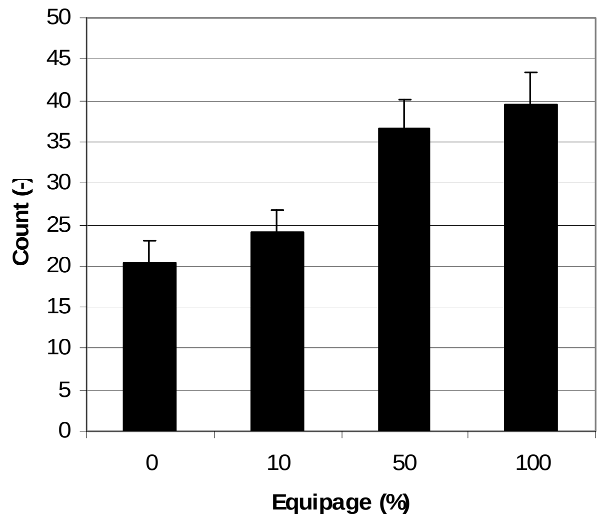


Figure 59. Number of undefined controller entries as a function of Data Comm equipage level.

3.3.8 Air Traffic Control Observer Ratings

For the equipage level treatment, we also ran a univariate ANOVA on each item, with the Bonferroni correction. Two items yielded statistically significant comparisons. Item 27, Overall Data Communication, showed a significant difference between the 10% and 100% Equipage conditions, $p < .001$ and between the 50% equipage and 100% equipage conditions, $p < .001$. Item 25, Communicating Efficiently, under the general heading Data Communications, showed a significant difference between the 50% equipage and 100% equipage conditions, $p < .001$, but not between the 10% and 100% equipage conditions, $p = .0134$. The means are plotted in Figure 60.

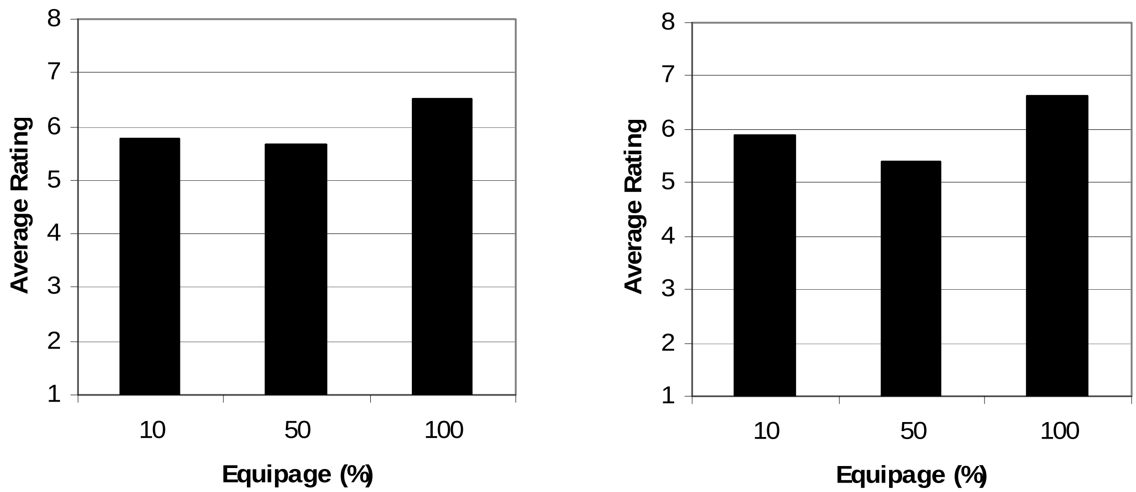


Figure 60. Overall data communication (left) and communicating efficiently (right).

3.3.9 Debriefing Comments

Five groups did not perceive a difference between the voice-only and 10% equipped conditions. Some controllers indicated that any reduction in voice communications was welcome. Controllers did point out that simulations with 10% of the aircraft equipped with Data Comm did not increase their workload.

For the 50% equipage condition, five of the seven groups indicated that it was easy to distinguish between Data Comm equipped aircraft and aircraft with voice only. The experiment included the 50% equipage conditions because others (Zingale, Willems, & Ross, 2010) had indicated that controllers might confuse equipped and voice-only aircraft in this condition. Our participants indicated that this was not the case.

Data Comm equipped aircraft received a MONITOR FREQUENCY message, so the pilots did not call in. We expected that this could affect their visual scan negatively. However, during the debriefing, two groups reported that even though the Data Comm equipped aircraft did not call in verbally when entering the sectors, it did not affect their visual scan of those aircraft. Most of the participants agreed that the higher equipage levels changed the way they worked traffic.

Most of the controller groups discussed the 100% equipage condition because they identified several challenges —even though it made controlling traffic easier. The controllers found that with 100% Data Comm, the R- and D-sides seemed to work much more independently, whereas with voice-based aircraft, they communicate verbally more often within the team. The controllers also indicated that the support function of the D-side is more difficult, because voice communication provides the D-side with information about which aircraft the R-side is working. Because Data Comm does not provide that verbal cue, the D-side controller cannot assist the R-side the same way.

We had noticed some reluctance of controllers to use voice communications when a higher percentage of the fleet had Data Comm equipage. The controllers shared with us that they felt that using voice was a failure of not using the available automation—even though we had stressed that controllers should use voice communications (not Data Comm) in tactical situations. Although controllers mentioned in general (one group hinted that they considered the Data Comm delay) that they had not changed their control strategy, it was surprising to see that only a few tactical voice clearances had occurred during the 100% equipage conditions.

3.4 Service Policy and Equipage Level

To promote the data communication equipage, the FAA may adopt the BEBS procedure instead of the current FCFS procedure. Using the PSQ ratings, we examined the interaction effect of the combinations of this procedure and equipage levels. We tested to see whether the benefit of the new procedure would depend on the number of aircraft that were Data Comm equipped. We compared two aircraft equipage levels, 50% and 10%, of the aircraft in the sector. Half of the total participants—that is, 12 participants—participated in the experimental runs of which the data we used to test this interaction between service policies and equipage levels; six participants worked on the R-side, and six participants worked on the D-side.

3.4.1 Push-To-Talk

We conducted a mixed 2 x 2 x 2 (Actor x Service x Equipage) analysis of variance on the number of PTT events, where Actor is a between group variable and Service and Equipage are repeated measures. We found similar results as for the Equipage design with an interaction between actor and equipage level, $F(1, 10) = 6.657$, $p < .05$). There was no effect of Best Equipped, Best Served on the number of PTT events. We conducted the same analysis on the duration of PTT events, but the duration did not differ across experimental conditions.

3.4.2 Workload

There was no difference in reported workload between the two policies.

3.4.3 Questionnaire Data

We summarized only the significant results of the controllers' ratings on the six tasks below. Table 31 shows the results about the control tasks, and Table 32 shows the results from the 17 ATC communication activities. The *z* values in the tables are based on negative ranks. There was no missing data in Table 31, so the number of data points of the cells was 12. In Table 32, there were many missing data, so we entered *n* for each cell to show how many data points we used for the results.

In both Tables 31 and 32 and in Figure 61, the results showed that the equipage level was the more critical factor than the service policy. There was not much difference between two service policies.

Table 31. Four Air Traffic Control Tasks That Showed Significant Results

Tasks	**Friedman Test Results**	**Wilcoxon Test Results Service by Equipage %**						
			FCFS&EQ10% vs. FCFS&EQ50%	**FCFS&EQ10% vs. BEBS&EQ10%**	**FCFS&EQ10% vs. BEBS&EQ50%**	**FCFS&EQ50% vs. BEBS&EQ10%**	**FCFS&EQ50% vs. BEBS&EQ50%**	**BEBS&EQ10% vs. BEBS&EQ50%**
Managing aircraft traffic sequences	$\chi^2 = 14.088$, $p = .003$	*z*	-2.037		-2.588	-2.222		-2.831
		p	.042		.010	.026		.005
Routing or planning flights	$\chi^2 = 12.226$, $p = .007$	*z*			-2.694	-2.012		-2.842
		p			.007	.044		.004
Assessing weather impact	$\chi^2 = 9.571$, $p = .023$	*z*			-2.399			-2.388
		p			.016			.017
Managing sector and position resources	$\chi^2 = 8.418$, $p = .038$	*z*			-2.546			
		p			.011			

Table 32. Three Air Traffic Control Communication Tasks That Showed Significant Results

Tasks	**Friedman Test Results (*df* = 3)**	**Wilcoxon Test Results FMS (F) by Equipage (E) in Percentage**						
			FCFS&EQ10% vs. FCFS&EQ50%	**FCFS&EQ10% vs. BEBS&EQ100%**	**FCFS&EQ10% vs. BEBS&EQ50%**	**FCFS&EQ50% vs. BEBS&EQ10%**	**FCFS&EQ50% vs. BEBS&EQ50%**	**BEBS&EQ10% vs. BEBS&EQ50%**
Route modifications: Current	$\chi^2 = 11.680$, $p = .009$, ($n = 9$)	*z*	-2.205 ($n = 9$)		-2.414 ($n = 12$)	-2.565 ($n = 11$)		-2.687 ($n = 12$)
		p	.027		.016	.010		.007
Crossing constraints: Altitude	$\chi^2 = 10.672$, $p = .014$, ($n = 7$)	*z*	-2.214 ($n = 7$)		-2.388 ($n = 7$)	-1.975 ($n = 8$)		-2.060 ($n = 8$)
		p	.027		.017	.048		.039
Voice frequency assignments	$\chi^2 = 12.623$, $p = .006$, ($n = 8$)	*z*	-2.032 ($n = 8$)		-2.032 ($n = 8$)	-2.041 ($n = 8$)		-2.392 ($n = 9$)
		p	.042		.042	.041		.017

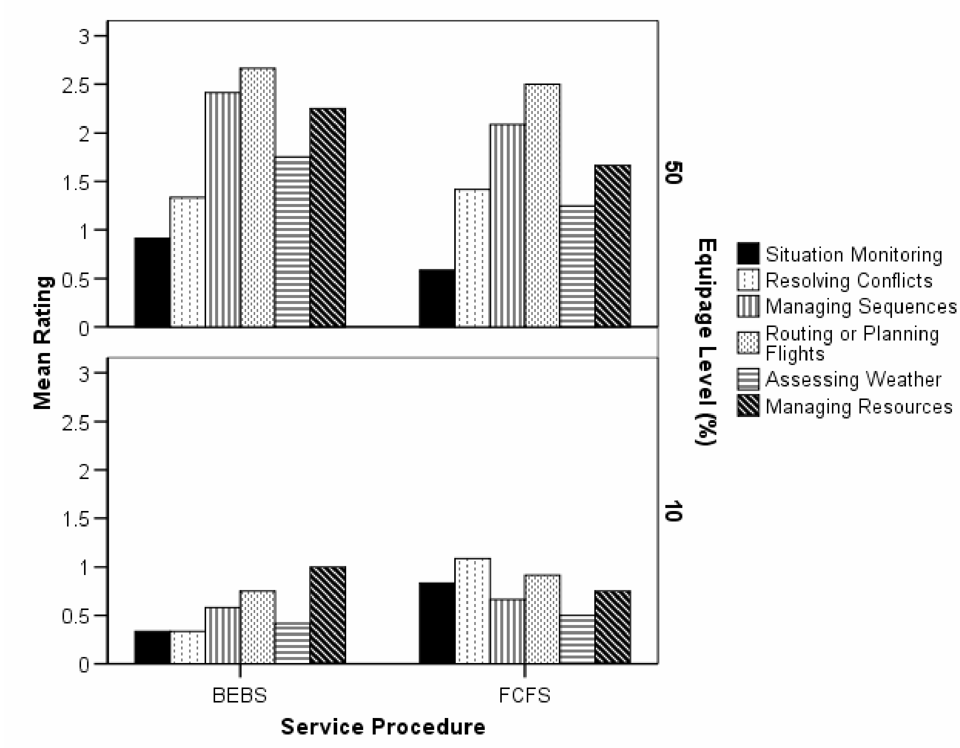


Figure 61. Mean ratings of service policy and equipage level combinations.

3.4.4 Target Generation Facility Data

We compared the Best-Equipped, Best-Served policy to the First-come, First-served policy for two levels of Data Comm equipage, 10% and 50%. Since all scenarios had a mix of data and voice communications, there were no zero counts; therefore we used a conventional ANOVA to analyze the results. Neither the main effect of Service Policy, nor any interactions with Service Policy, was statistically significant, for any of altitude, route or crossing clearances.

3.4.5 Functional Near Infrared Data

We analyzed oxygenation changes as a function of equipage level (10% or 50% equipped) and service policy (BEBS or FCFS). We set our data up in a manner that included controller position, equipment level, and service policy as independent variables. If the analysis revealed main effects or interactions that did not involve service policy, we will not discuss them here, because we have addressed them in other experimental designs.

In general we did not find an effect of service policy on oxygenation changes. The exception was Voxel 16, where oxygenation levels decreased for the BEBS condition and increased for the FCFS condition, $F(1, 8) = 8.501$ at $p < .05$. The results for Voxel 11 suggested an interaction between the effect of controller position and service policy, $F(1, 8) = 7.133$ at $p < .05$. We tested simple effects, but found that there were no differences for controller position within BEBS or FCFS nor were there differences for service policy within each of the controller positions.

3.4.6 Controller Entries

We analyzed the controller entries as a function of service policies and equipage levels. None of the results that were statistically significant involved the service policies variable.

3.4.7 Air Traffic Control Observer Ratings

For each of the Service policy by Equipage and FMS Integration by Equipage series, we ran a univariate ANOVA on each item, with the Bonferroni correction. There were no significant differences in ratings across the experimental treatment for any item, for either of these test series.

3.4.8 Debriefing Comments

Three of the seven groups did not believe that BEBS was feasible the way we had implemented it in this experiment. Five of the groups suggested that either automation or traffic flow could implement BEBS better than the controller at the sector. Four of the groups suggested that it was often easier to move the better equipped aircraft and moving the lesser equipped aircraft would have been counterintuitive.

All groups believed that a mandate for equipage in certain airspace would provide BEBS without the complexity of the controller needing to decide to whom to give priority. All controllers agreed that when safety is an issue, they would not consider BEBS. As one controller put it, *BEBS has a third-level priority after safety and efficiency.*

3.5 Equipage Level and FMS Integration Interactions

3.5.1 Push-To-Talk

We conducted a mixed 2 x 2 x 2 (Actor x Integration x Equipage) ANOVA on the number of PTT events, where Actor was a between group variable and Integration and Equipage were within group variables. We found similar results as for the Equipage design. We found an interaction between Actor and Equipage level, $F(1, 10) = 6.657$, $p < .05$). There was no effect of FMS Integration on the number of PTT events.

We conducted the same analysis with the duration of PTT events, but we did not find any significant difference across experimental conditions.

3.5.2 Workload

Subjective ratings of workload were low overall and did not differ significantly between R-side and D-side controllers. There was a significant difference between the 50% and 100% FMS integration conditions, $F(1, 10) = 15.914$, $p < .003$, but no significant difference between 50% and 100% data communication equipage conditions, $F(1, 10) = 1.625$, $p = .231$ (see Table 33 and Figure 62).

Table 33. Mean WAK Ratings for FMS Integration and Equipage Levels

	50% FMS Integration	**100% FMS Integration**
50% Data Comm Equipped	3.40	2.64
100% Data Comm Equipped	2.99	2.61

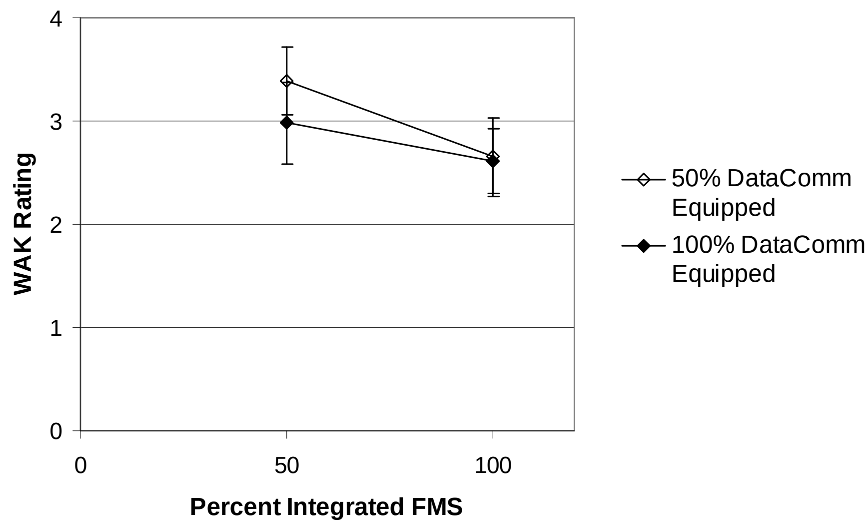


Figure 62. Subjective workload as a function of data communication equipage level by integrated FMS level.

3.5.3 Questionnaire Data

We analyzed two types of questionnaire data: PSQ and Exit Questionnaire. For the PSQ, we tested if the four combinations of the equipage levels of 50% and 100% and FMS integration levels of 50% and 100% were significantly different using the Friedman test. If the Friedman tests were significant, we tested the pairs of these combinations using Wilcoxon Matched-Pair Rank tests as a post hoc test. First, we tested them on the six major tasks and 17 communication tasks. The Friedman test on one of the major six tasks, Managing Sector and Position Resources, showed a significant result (see Table 34). Table 34 also shows the significant results of the pairwise comparisons. There was no missing data in each cell, so *n* was 12. The pairwise comparison test results did not show a clear pattern.

Table 34. The Significant Results of Ratings on the Task of Managing Sector and Position Resources

Tasks	**Friedman Test Results**		**Wilcoxon Test Result** **FMS (F) by Equipage (E) in Percentage**					
			F50 & E50 vs. F50 & E100	**F50 & E50 vs. F100 & E50**	**F50 & E50 vs. F100 & E100**	**F50 & E100 vs. F100 & E50**	**F50 & E100 vs. F100 & E100**	**F100 & E50 vs. F100 & E100**
Managing sector and position resources	$\chi^2 = 10.121$, $p = .018$, ($n = 12$)	*z*			-1.983	-2.251		-2.354
		p			.047	.024		.019

Among 17 communication tasks, 3 tasks showed significant results by Friedman tests. But one of the tasks, heading changes, did not show any significant pairwise comparisons. Table 35 shows the significant results of pairwise comparisons for the other two tasks. Again, the results did not show a clear pattern.

Table 35. The Significant Results of Ratings on the Tasks of Route Modifications: Current and Heading Changes

Tasks	Friedman Test Results (df = 3)		Wilcoxon Test Results FMS (F) by Equipage (E) in Percentage					
			F50 & E50 vs. F50 & E100	F50 & E50 vs. F100 & E50	F50 & E50 vs. F100 & E100	F50& E100 vs. F100 & E50	F50 & E100 vs. F100 & E100	F100 & E50 vs. F100 & E100
Route modifications: Current	χ^2 = 13.020, p = .005, (n = 12)	z						-2.264 (n = 12)
		p						.024
Heading changes	χ^2 = 12.208, p = .007, (n = 12)	z			-2.000 (n = 12)	-2.489 (n = 12)		-2.209 (n = 12)
		p			.046	.013		.027

When we asked the participants of these combinations in the Exit Questionnaire, directly, they favored the 100% FMS level over the 50% FMS level. Their mean rating on controlling air traffic when there was a mixture of 50% aircraft equipped with data communication and 50% aircraft equipped with FMS was 2.25 (SD = 1.96) on the scale from -5 (*very limiting*) to 5 (*very useful*). We asked the same question when all aircraft were equipped with FMS and 50% of them were also equipped with Data Comm; their ratings were more favorable, (M = 3.92, SD = 1.6). When we compared these two conditions (50% of FMS vs. 100% FMS when 50% of the aircraft had Data Comm capability), the Wilcoxon Matched-Pair Rank test showed a significant difference between them, z = -2.687, p = .007 (see Figure 63).

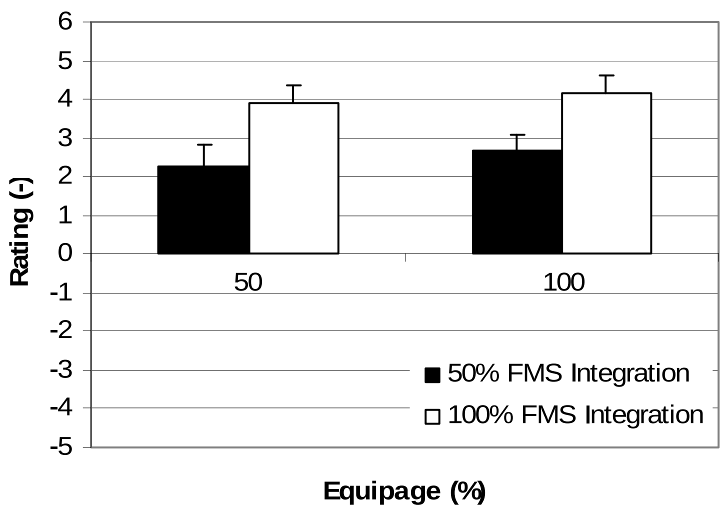


Figure 63. Ratings of both R- and D-sides on the combination of Data Comm equipage level and FMS integration level.

We asked the participants the same question when all aircraft had data communication capability (100%). Again, they favored the situation where all aircraft had FMS integrated over the situation where only 50% of the aircraft had FMS integrated. Their mean ratings were 2.67 (*SD* = 1.5) and 4.17 (*SD* = 1.6) on the scale from -5 (*very limiting*) to (5 (*very useful*), respectively. The Wilcoxon Matched-Pair Rank test showed the difference was significant, $z = -2.807$, $p = .005$ (as shown in Figure 63).

3.5.4 Target Generation Facility Data

We simulated nonintegrated FMS by increasing delays in the pilots' responses (adding time for manual transfer of clearance parameters). This increased the likelihood of message timeouts. We used levels of equipage of 50% and 100% and within each of those, levels of 50% and 100% FMS integration.

For this analysis, we included only the specific aircraft which were Data-Comm equipped in all scenarios, flying the same flight plan in each. Within this group we chose the two subsets which had integrated FMS in some scenarios, but not in others. One subset of 24 flights occurred in the 100%-Equipage/50%-Integrated and the 100%-Equipage/100%-Integrated scenarios only. We compared the total numbers of altitude, route and crossing clearances using paired *t*-tests with the Bonferroni correction to set the overall probability of Type I error at .05. There were no significant differences in numbers of clearances when the aircraft had Integrated FMS versus when they had not. Another subset of 28 flights occurred in all four scenarios. We compared the total numbers of altitude, route and crossing clearances within the two 50%-Equipage scenarios; and separately within the two 100%-Equipage scenarios. In one of the two scenarios, the aircraft had Integrated FMS; in the other scenario they did not. Again, no statistically significant differences were seen, using paired *t*-tests with the Bonferroni correction, between the scenarios in which the aircraft had Integrated FMS and those in which they did not.

3.5.5 Controller Interactions

We analyzed the controller entries as a function of FMS integration and equipage level. None of the significant results involved the FMS integration variable.

3.5.6 Debriefing Comments

Six groups indicated that controllers needed to know if an aircraft had an integrated FMS. The controllers differed in opinion about how the system should show that an aircraft has FMS integration. Some suggested that there is too much information in the data block already. Others suggested that it might not be practical to use the aircraft type suffix, because there are too many of them already. Some controllers suggested using color to indicate FMS integration. Some controllers mentioned that they would be more conservative in giving clearances to aircraft that did not have an integrated FMS.

Three of the groups suggested that when in a mixed environment controllers would assume the worst case and treat all aircraft as if they did not have FMS integration. Two other groups suggested that they would treat all aircraft equally and leave it to the pilot to let controllers know whether a particular clearance was too complex to execute. Because of the way in which we had implemented FMS integration (nonintegrated aircraft took longer to respond), controllers suggested that we needed to make a better distinction between message time-outs, message failures, and UNABLE and STANDBY responses.

3.6 Data Communications Failure

In the Individual Aircraft Failure test scenario, six aircraft lost Data Comm during the 50 minutes of traffic flow. The first failure occurred at 00:08, the remaining failures occurred at 5- and 9-min intervals; and the last failure occurred at 00:43.

After 30 minutes of the experimental run, we simulated either a *partial failure* (Teams 4, 7, 8, 10, 11, 12, and 13)—Note: We call them Group A in this section. This Group A and Group B differentiation in this section is different from that shown in Groups A and B in Table 2. One team in the Group A in Table 2 was originally assigned to experience the system failure but actually experienced the partial failure instead—or a *complete system failure* within the sector (Teams 3, 5, 6, 9, and 14). Note: We call them Group B in this section. The failure (whether partial or system-wide) occurred at 30 minutes into the run and continued to the end at 50 minutes.

3.6.1 Push-To-Talk

To determine the effect of Data Comm failure type on the number and duration of PTT events, we assigned controllers to two groups. One group (Group A) consisted of controllers that experienced the partial failure, where only part of the airspace suffered from a loss of data communications. The other group (Group B) consisted of controllers that experienced system-wide failure. Controllers in both groups experienced the baseline condition without data communication failures as well as the condition with data communication failure of individual aircraft. We conducted a mixed 2 x 2 x 3 (Actor x Group x Failure Mode) analysis, where failure mode represented partial and system-wide data communication failure, respectively. Our analysis revealed a main effect of actor similar to what we had found in other analyses, $F(1, 20) = 27.632$, $p < .05$, a main effect of failure mode, $\Lambda(2, 19) = .152$, $F(2, 19) = 52.996$, $p < .05$, and an interaction between group and failure mode, $\Lambda(2, 19) = .537$, $F(2, 19) = 8.207$, $p < .05$. Because we found an interaction between group and failure mode, we performed a Tukey's HSD post hoc test and found that the number of PTT events of both groups did not differ between groups for the baseline or the individual aircraft failure conditions. The number of PTT events of Group A during partial failure was significantly higher than those of the No Failure condition, but was not higher than those of the individual aircraft conditions. The number of PTT events of Group B during the system-side data communication failure was significantly higher than those during all other conditions (see Figure 64).

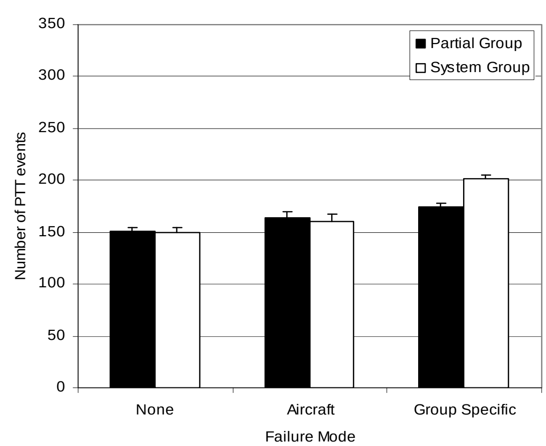


Figure 64. Number of PTT events as a function of failure mode.

3.6.2 Workload

For the Individual Aircraft Failures, we analyzed between 4th and 23rd WAK responses which occurred after the first failure and afterwards. Overall, the reported workload was slightly higher for the Individual Data Comm Failure test run than for the control run, in which no failure occurred (mean WAK Rating of 3.6 vs. 3.2), but the difference was not statistically significant.

The partial or system-wide failure occurred at thirty minutes into the experimental run and continued to the end of the experimental run, 50 minutes. Therefore, the last nine WAK ratings, from 30 minutes to 46 minutes, occurred after the failure. For the analysis, we compared these to the nine ratings that occurred just preceding the failure (i.e., during normal operation) from 12 minutes through 28 minutes. The same analysis was also performed on the *omnibus* control scenario, in which all other experimental parameters were the same. This provides a statistical correction for the effect by traffic level- and time-dependent effects without the effect of failure. If either or both failure types increased the controllers' workload, it should appear as an increase from the early ratings to the later ratings, greater than any increase seen when no failure occurred. Therefore, we would expect a significant interaction of the Early/Late Rating factor with the Failure/No Failure factor. If one type of failure causes a greater increase in workload than the other, we would expect a three-way interaction, (Early/Late Rating) by (Failure/No Failure) by (Failure Type).

We analyzed the data treating Failure Type and Controller Position as between-subjects factors, and Early/Late Probe and Failure/No Failure as within-subjects factors, using the General Linear Model analysis procedure in STATISTICA™.

There is an increase in reported workload from the earlier to later probes; this was statistically significant, $F(1, 20) = 31.658$, $p < .01$. The results show this as upward-sloping graphs for both control (no failure) and failure runs (see Figure 65). The teams that experienced the System failure gave significantly higher workload ratings than the teams who experienced a Part-Airspace failure, $F(1, 20) = 10.658$, $p < .01$. Figure 65 clearly shows this group difference for the control run in which no failure occurred as well as for the failure scenario. The steeper slopes of the lines for the failure conditions, compared to the no-failure conditions, suggest a specific increase in workload due to failures. However, this apparent trend, represented by the interaction Early/Late Probe by Failure/No Failure, was not statistically significant.

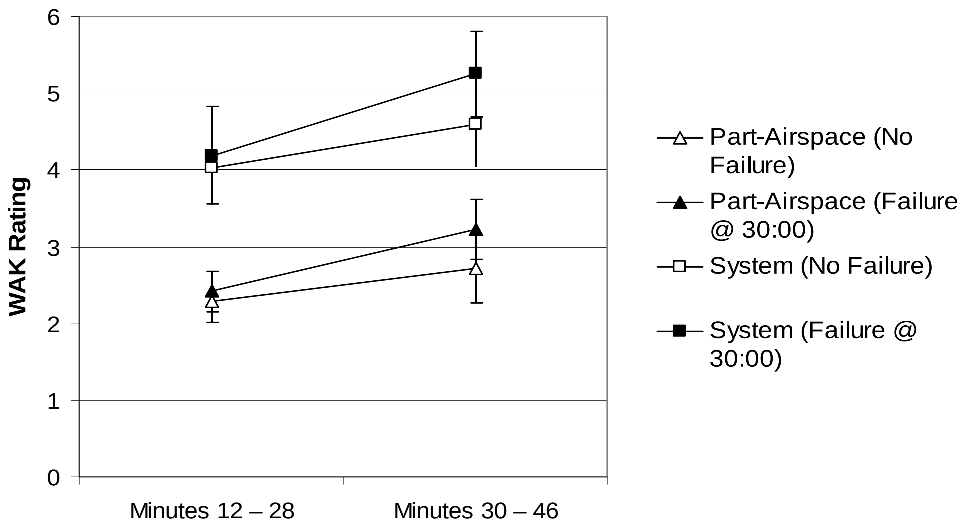


Figure 65. Average subjective workload preceding and following partial and system-wide data communication failures.

3.6.3 Questionnaire

In our experimental design, as described above, the participants experienced only three failure modes: Seven teams (Group A) experienced no failure, individual aircraft failure, and partial failure, and the rest of the participants. Five teams (Group B) experienced no failure, individual aircraft failure, and system failure. We analyzed the data of these two groups separately.

The controllers rated the positive or negative aspects of Data Comm in the PSQ after the experimental run that had the data communication failure. Neither R-side nor D-side rating data showed statistically significant differences among failure modes, except the rating on assessing weather impact by D-side controllers. These D-side controllers experienced no failure, individual aircraft failure, and no system failure. The Friedman test ratings showed there was a significant difference among the three failure modes ($\chi^2 = 7.625$, $df = 2$, $p = .022$). The Wilcoxon Matched-Pair Rank post hoc tests showed that ratings with the system failure were significantly lower (mean rating: 1.5) than those with individual aircraft failure. The mean rating was 2.9 on a scale of -5 (*hindered greatly*) and 5 (*helped greatly*), $z = -2.121$, $p = .034$. The results showed that Data Comm helped the controllers control traffic better when individual aircraft failure occurred than when they had a full system failure.

One segment of the Exit Questionnaire was about failure modes. We asked the participants to rate the effect of data communication failure on a scale between 1 and 10 (1 = *not detrimental at all*, 10 = *very detrimental*). Each group of participants experienced only two types of failure modes. We compared the pooled R- and D-side ratings of individual aircraft failure with those of partial failure of seven teams and ratings of individual aircraft failure with those of total failure of five teams. Both comparisons showed significant results ($z = 2.836$, $p = .005$) between individual aircraft and partial failures (Group A) and ($z = -2.812$, $p = .005$) between individual aircraft and total failures (Group B); see Figure 66 and Figure 67. Both partial and total failures were more detrimental in ATC than individual aircraft Data Comm failure.

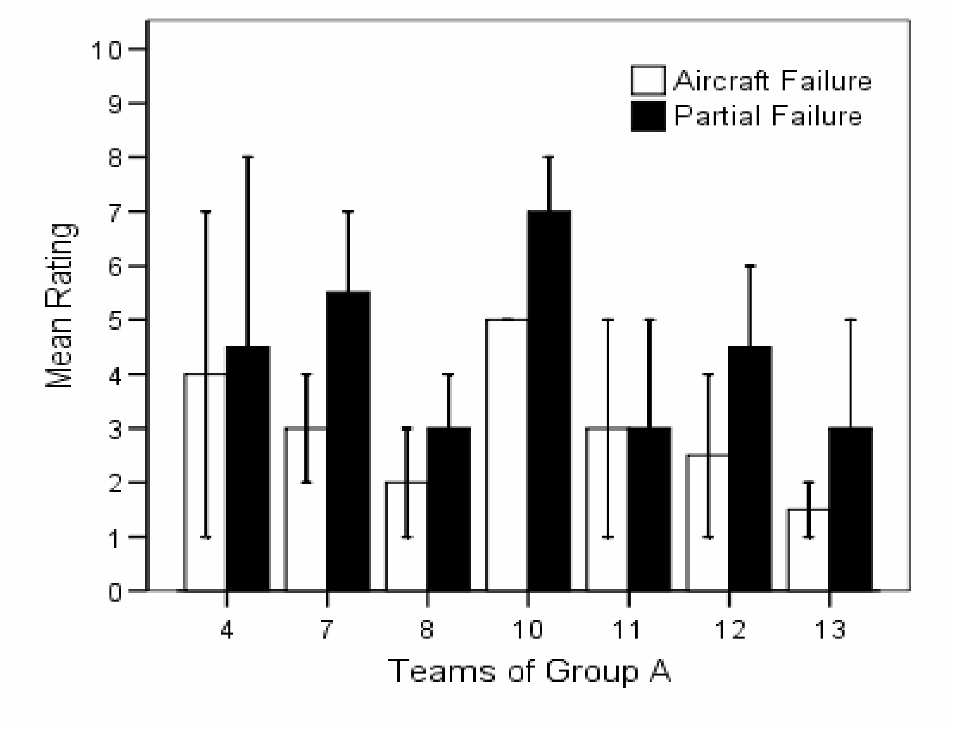


Figure 66. Mean ratings about the effect of aircraft and partial failures.

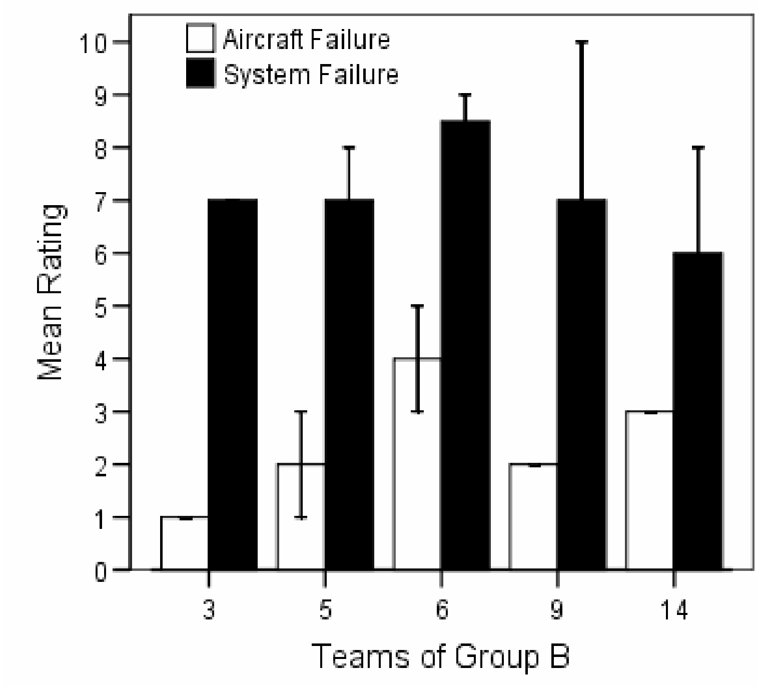


Figure 67. Mean ratings about the effect of aircraft and total failures.

We also tested if the ratings of partial and total system failures would be statistically different. Because the numbers of ratings of the two groups were different, we used two-tailed independent t tests. The results showed that there was no statistical difference between the ratings of aircraft failure mode between two groups, but showed that the participants rated the system failure (M = 7.10, SE = 1.969) more detrimental than the partial failure (M = 4.36, SE = 2.499), t = 2.743, p = .009.

3.6.4 Target Generation Facility Data

3.6.4.1 Individual Aircraft Failures

The first individual aircraft failure occurred around 8 minutes after the start of the experimental run. The next aircraft failures occurred at the intervals between 5 and 9 min. In total, there were six individual aircraft failures for an experimental run.

We compared the number of altitude, route, and crossing clearances that controllers issued to the six aircraft to clearances given to the same aircraft in the baseline control condition. The results did not show statistically significant differences between these two groups of aircraft.

3.6.4.2 System or Partial-Airspace Failure

System or Partial-Airspace Failures occurred at 30 min into the test runs. We defined two time intervals for comparison: before failure (from 12 min to 30 min), and after failure (from 30 min to 48 min). We compared these time intervals to the same intervals within Test Run 4, the baseline control condition, which was identical in all other parameters: HMI, equipage level, FMS integration, service policy, and system delay. If the failures did not disrupt controller performance, we would expect to see them issue the same number of clearances following the failures; the only difference is that they had to use voice communication for the Data Comm failed aircraft. We analyzed the total numbers of altitude, route, and crossing clearances, regardless of the communication mode used. We did not find any significant interaction between failure/no failure and before/after, indicating that controller performance was not disrupted.

3.6.5 Debriefing Comments

3.6.5.1 Individual Aircraft

When an aircraft lost a Data Comm session, the Data Comm symbol of the aircraft changed from a filled square to an open triangle in our simulation. Five out of the seven groups indicated that this indicator was not salient enough to capture their attention. They suggested making the loss of a Data Comm session more salient using different color, flashing of the Data Comm status indicator, or a change of the call sign to draw a controller's attention. In the case of an individual aircraft Data Comm loss, the participants stated that they just reverted to voice for these aircraft.

3.6.5.2 Partial System Failure

Several of the groups indicated that it is easier to revert in a mixed environment, because there are still some aircraft that require voice communications.

3.6.5.3 Full System Failure

Two out of the seven groups expressed that it would not be safe to revert to voice when maintaining the same traffic levels (150% of current Monitor Alert Parameter value). Three of the groups felt that it was safe to revert to voice, but it would require additional personnel to help during the transition. These groups also indicated that controllers who have worked under voice-only conditions for most of their careers, reverting to voice might not be an issue. However, they expressed their concern that this may not be the case for controllers who have worked with Data Comm at high equipage levels for a long time. Some controllers suggested that controllers might need to train for a loss of Data Comm event. The other two groups indicated that it would be safe to revert to voice, but it would increase workload during the transition.

3.7 End-to-End Technical Delays: Segment 1 vs. Segment 2

3.7.1 Push-To-Talk

We conducted a mixed 2 x 2 (Actor x Segment) analysis of variance on the number of PTT events, where Actor is a between group variable and Segment is a repeated measures variable. We found an effect of Actor, $F(1, 22) = 25.522$, $p < .05$, similar to what we found in the other analyses.

Our analysis of the duration of PTT events as a function of Actor and Segment 1 and 2 delays showed only a significant difference between the duration of controller and pilot commands, $F(1, 22) = 6.99$, $p < .05$. Although the difference was significant, it was small (300 ms).

3.7.2 Workload

We compared the Segment 2 Delay Run to a control run that was identical with respect to all other parameters. There was no effect of delay on reported workload.

3.7.3 Questionnaire Data

There was a significant rating difference between two sets of delays on the scale of 1 (*not detrimental at all*) to 10 (*very detrimental*). We compared the 8-second set and 30-second set with the 5-second set and 10-second set for critical and noncritical messages, respectively. The Wilcoxon Matched-Pair Rank Test showed that controllers rated the 5 and 10-second set (M = 3.21) less detrimental than the 8-second set and 30-second set (M = 5.58), $\chi^2 = -3.101$, $p = .002$, $n = 21$.

3.7.4 Target Generation Facility Data

There were no statistically significant differences between the numbers of altitude, route, or crossing clearances that controllers issued in the test run with Segment 2 technical delay, compared to Segment 1.

3.7.5 Debriefing Comments

None of the groups had noticed that in one of the scenarios the pilot delay times were significantly shorter. However, one of the groups commented that they believed they were leading the aircraft (i.e., providing clearances using Data Comm earlier to account for the Data Comm delay). Two of the groups commented on the delay times being too long to use Data Comm for sequencing and spacing, because in those situations they wanted a fast pilot response.

3.8 Exit Questionnaire on Experimental Factors

3.8.1 Evaluation of Data Communication Features

We identified 26 data communication features and asked controllers to rate them on a scale ranging between -5 (*hindered greatly*) and 5 (*helped greatly*), as they had experienced them during the experiment (see Appendix E). The mean ratings of all items showed positive values, except Item 10: *Displaying and modifying trajectory through template* (M = -2.148, SE = 2.282) and Item 14: *Updating conflict probe status when graphically modifying a trajectory* (M = -1.000, SE = 2.582). The ratings of Item 10 were significantly different from 0 (*neutral value*), t = -4.891, $p < .001$. The ratings of Item 14 were not significantly different from 0. All other items showed positive mean values, and t-tests of the ratings for Items 1, 3, 4, 6, 7, 8, 9, 11, 16, 17, 18, 19, 20, 22, 23, 24, 25, and 26 (18 items total) showed a significant difference from the neutral value, 0 (see Appendix E for the detailed description of the items). For all other items, t-tests did not show significant results.

3.8.2 Simulation Realism and Research Apparatus Ratings

We asked the participants to rate what they thought about the simulation experiment. Among seven questions, three questions were about the realism of the experiment, including the overall experimental environment, scenarios, and generic airspace. Two questions were about the equipment they used: Air Traffic Workload Input Technique (ATWIT) and oculometer. We asked them to rate whether the equipment hindered their air traffic control performance, using a scale ranging from 1 (*not at all*) to 10 (*a great deal*). We also asked them to evaluate the pilots' performance on clearances and callbacks. Lastly, we asked participants whether the training that they had received was effective; all means of the ratings were above 5, except the scenario realism and the interference of the ATWIT. The t-tests on airspace, t = 2.922, p = .007, ATWIT, t = -5.484, p = .01, and pilots' performance, t = 2.914, p = .007, were significant. Participants rated that the airspace was realistic, that ATWIT did not hinder their air traffic control performance, and that pilots' responses to clearances and callbacks were effective. Other t-tests were not significant.

3.9 Air Traffic Control Observer Ratings

We also ran a factor analysis on the items in the form (the detailed results of the analysis are presented in Appendix H). Factor analysis is a technique for identifying a small number of dimensions that summarize, as much as possible, the information obtained from a larger number of measures, such as the 31 OTS scales. We identified and named five factors underlying the OTS ratings:

- Factor 1: Communicating Clearly and Efficiently
- Factor 2: Strategic Air Traffic Control
- Factor 3: Tactical Air Traffic Control
- Factor 4: Situation Awareness
- Factor 5: Providing Information

3.10 Proximity Events

Twelve teams of R- and D-side controllers had 12 experimental runs, resulting in a total of 144 runs. There were 10 proximity incidents over the entire simulation experiment, excluding those proximity events attributable to either simulation pilot errors or system malfunctions. The small number of proximity events did not lend itself for inferential statistical analysis. In Table 36, we describe the overall patterns of the proximate incidents. We present detailed descriptions of the proximity incidents in Appendix I.

Table 36 also shows the frequency of proximity events by the equipage level. At the bottom of the table, we entered the frequency, percentage, and total experimental runs in the experiment for each equipage level. The table also shows the experimental parameters in those runs (service policy, HMI, failure mode - aircraft, partial, or total, system delay, and FMS, equipage level) that had the proximity incidents.

There were no proximity events in the voice-only or in the 10% equipage runs. There were 6 proximity incidents in 50% equipage levels and 22 proximity incidents in 100% equipage levels, respectively. Although the numbers of proximity events were not large, the results showed that controllers had more proximity events in higher equipage levels.

Table 36. Proximity Incidents by Different Experimental Conditions

						Equipage Level (%)			
Team	**Service Policy**	**HMI**	**Failure**	**Delay**	**FMS Integration (%)**	**0**	**10**	**50**	**100**
04	FCFS	Template	N	Segment 1	100			1	
05	FCFS	Combined	N	Segment 1	100				1
06	FCFS	Combined	N	Segment 1	100			1	
08	FCFS	Combined	P	Segment 1	100			1	
09	FCFS	Combined	N	Segment 1	100			1	
09	FCFS	Combined	N	Segment 1	100				1
10	FCFS	Combined	N	Segment 1	100			1	
10	FCFS	Combined	N	Segment 1	100				1
13	FCFS	Template	N	Segment 1	100			1	
13	FCFS	Combined	N	Segment 1	100				1
Percentage of proximity events (%)						0	0	6	22
Number of proximity events						0	0	6	4
Number of simulation runs						12	18	96	18

3.11 Eye Movement Data

We have currently only analyzed the general fixation data on scene planes including the R-side and D-side display. In general, we found that controllers looked at their own displays and did not spend much time scanning the display of the other controller. Figure 68 shows the distribution of fixations across teams for the 10% equipage condition as an example.

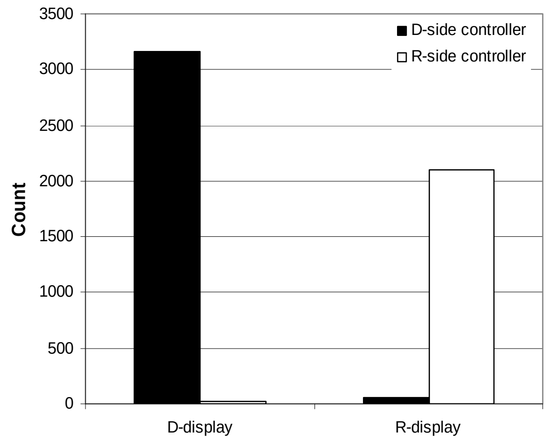


Figure 68. Number of eye movement fixations as a function of controller position and controller display.

3.12 General Debriefing Comments

3.12.1 Simulation Training

Two of the groups mentioned that they needed more practice at lower traffic levels. Although we realize that the amount of practice was insufficient to become fully proficient in using the airspace, ERAM, and data communication capabilities, we counterbalanced the experimental conditions to mitigate a potential training effect.

Three of the groups indicated that they started to recognize the scenarios because we had only changed aircraft call signs. One of these groups commented that this is true in the field as well. Although we recognize that there will be a training effect, as we stated earlier, we mitigated that by counterbalancing the experimental conditions.

3.12.2 D-side Activities

Six groups commented that with the level of traffic and weather activity in the sector, the D-side in the field would have a lot of coordination with adjacent sectors and facilities. The controllers suggested that the simulation would have been more realistic if it included point outs, approval requests, and other coordination activities between the D-side controller and adjacent sectors or facilities. Several of the controllers suggested that electronic coordination similar to the air-to-ground data communication capabilities could alleviate the amount of landline communications when the D-side needs to coordinate with adjacent sectors or facilities. Some of the controllers assumed that an implementation of data communication would include electronic ground-to-ground communications as well.

3.12.3 Pointing Device

Although the response to the use of a mouse instead of the standard trackball was positive, three of the groups mentioned that the wheel on the mouse as the center button was a hindrance. In this experiment, the interface had no functions that required scrolling and the controllers therefore did not see the use of having a wheel on the computer mouse.

3.12.4 Placement of Data Comm Hot Key

To assist in data entry, we had implemented a hotkey that appended a [space]DL[enter] sequence to a NAS entry, thereby updating the NAS and sending the appropriate message to the aircraft using data communication. Three of the groups suggested moving the location of the hotkey because we had used one of the [space] keys on the numeric keypad. In the field, controllers often use that key for fast entries that use only the numeric keypad.

3.12.5 Feedback

Several controllers indicated that it might be necessary to indicate that an entry requires a voice clearance although our interface forced controllers to make a decision between a NAS entry only and a combination of a NAS entry and an uplink.

3.12.6 Ability to Cancel a Data Comm Message

Three groups suggested that they should be able to cancel a Data Comm message. When we explained that using Data Comm for that purpose could be futile because of the potential delays, they emphasized that we should establish clear phraseology for controllers to cancel Data Comm messages.

Controllers had similar concerns about messages on the data block that timed out. In our implementation, when a message timed out, it blinked. Controllers could suppress the blinking and remove the notification, but they indicated that it should be clearer to them about what would happen if they decided to suppress it. That is, would it still be possible for a pilot's response to arrive, or was the message canceled? If controllers need to verbally cancel a timed-out Data Comm message, they recommended using the same canceling phraseology to communicate it to the pilot.

3.12.7 Weather Advisories

Six of the seven groups brought the use of data communication for weather advisories or weather information to our attention. One of the issues controllers addressed was that when giving a voice clearance to an aircraft, controllers frequently attach a reason for the clearance. The controllers suggested that it would be helpful to have the option to add a reason, such as weather, spacing, or traffic. Another suggestion controllers made was to be able to provide SIGMET, PIREP, and Notice to Airmen (NOTAM) to data communication equipped aircraft on initial contact. This would reduce the amount of frequency congestion not only because the controller would not need to provide the information to the aircraft (that would only benefit airspace with 100% of the aircraft equipped) but also because pilots would not call in to request ride quality, and so forth.

3.12.8 Miscellaneous

Here we will capture controller comments that were to infrequent to form a theme but still important enough to mention. We will also include comments related to aspects of the simulation environment that we did not test in this experiment but are useful to document for future activities.

3.12.8.1 Sector Staffing

The current experiment exposed controllers to approximately 150% of current MAP values. The controllers commented that as a rule of thumb at some of the facilities, controllers will work by themselves up to 50% of the MAP value. Between 50% and 100% of the MAP value, a two-person team will staff a sector. Finally, between 100% and 150% of the MAP value an R-side, a D-side, and a tracker will staff the sector. As a result, many of our participants felt that the traffic levels were high even with Data Comm available because they compared these levels with what is currently acceptable in the field.

3.12.8.2 Conflict Probe

Four of the groups commented that the implementation of the conflict probe in our simulation environment did not work well. Although this experiment did not focus on the use of a strategic conflict probe, we implemented an integration of conflict probe on the radar display. The simulation environment depicted a potential scenario, where the D-side workstation had evolved and contained an integrated radar display. To accommodate that environment, we integrated conflict detection into the radar display. The controllers could see when the conflict probe detected a conflict in a similar fashion as the User Request Evaluation Tool displays it in the field. When the controllers pulled up the trajectories for these potential conflicts, they indicated that our probe did not work as well as the system in the field.

The controllers commented that if the probe would be working well they preferred an integrated approach instead of probe data displayed on an auxiliary display. One group of controllers suggested that it might be useful to show additional conflict information when hovering the cursor over the conflict indicator (e.g., showing time to loss of separation).

3.12.8.3 Automatic Handoff

One of the groups commented that automatic handoff worked well in our simulation environment, but in the field it does not always work. This may be due to a difference in algorithms between our simulated environment and the operational system that determines when the system will automatically hand off an aircraft to the next sector. When an aircraft is on FLAT, the aircraft is following its stored route within adapted conformance bounds. The operational automation should automatically hand off a FLAT tracking aircraft to the next sector when the aircraft passes a waypoint or transition line. The automatic handoff function reduces controller workload by automating the manual handoff. In a manual handoff, a controller has to monitor the position of an aircraft relative to the sector bound and initiate the handoff to the next sector. Some controllers indicated that the automation in the operational environment did not always work, thereby requiring them to monitor all aircraft to ensure that the automation executed the handoff correctly.

3.12.8.4 Pilot Reroute Request Display

Two groups mentioned that it would be useful to be able to display a pilot reroute request instead of only seeing the textual request. Although trajectory display and conflict probe of pilot requests may have been part of the initial requirements that we obtained from our cognitive walkthroughs and demonstration, we did not implement these capabilities for this experiment. Some of our controllers suggested that we should include these capabilities for future experiments.

3.12.8.5 Draft Data Communication Message

One of the groups suggested that it would be useful to be able to create a draft message that the controller or the system could send as soon as an aircraft becomes eligible. Controllers brought this to our attention because when a controller accepted a handoff from another sector, the way we had implemented Transfer of Communications (TOC) eligibility would only become available after a WILCO from the aircraft. Therefore, instead of waiting for the eligibility to come across, they would have preferred to create a message that would activate as soon as the aircraft became eligible. As one controller phrased it, with voice, they often take a handoff and give a clearance immediately.

In our implementation, controllers were not able to uplink a message until the TOC had completed. The final implementation will most likely have an immediate transfer of eligibility followed by a TOC. Depending on how the operational services will implement data communications specific procedures controllers may be able to uplink a clearance to an aircraft as soon as they have eligibility (similar to allowing a controller to maneuver an aircraft in outside of the sector as soon as the pilot has called in).

3.12.8.6 Complex Clearances

This experiment did not explicitly test differences between the use of a limited and an expanded message set. Our participants, however, commented on the use of more complex messages. Several of the groups indicated that they did not anticipate that controllers would use many of the complex clearances. When discussing complex clearances, the controllers would compare them with the complex clearances that exist in standard voice-based phraseology. Although complex phraseology already exists, it is more prone to misinterpretation and results in a larger burden on controller memory both during construction of the clearance and during monitoring of the execution of the clearance. In the future, this may change depending on the ease of creating clearances and the level of automation available to assist in monitoring proper execution of these clearances.

3.12.9 Roles and Responsibilities

All groups agreed that the availability of Data Comm for the D-side together with the availability of a radar display could create a drastic change in roles and responsibilities. All groups mentioned that in today's world, D-side controllers do not issue clearances and changes to roles and responsibilities will be necessary.

Most groups agreed that roles and responsibilities would have to change in the future and more so with the availability of Data Comm. The controllers mentioned that this in many cases would mean a change in the mindset of the workforce. The controllers indicated that with the availability of a radar display on the D-side position and Data Comm, the D-side controller could get much more involved in control of the sector. The controllers expected that the D-side controller might get more responsibilities than she currently has. However, they agreed that there would still need to be one person in charge of the sector.

Three of the groups suggested that it would be useful to show who took action. Two of these groups also suggested showing that someone else was manipulating a flight to prevent execution of the same or overwriting an action implemented by the other controller.

3.12.10 Training

We asked our controller groups how much training on Data Comm they would need before feeling comfortable to use it for field operations. Most responses indicated that for the most frequently used clearances, they only need a full day of training, but to use the full message set it would take a lot longer. Although the controllers suggested that elements such as symbology and basic interactions lend themselves for computer-based instruction (CBI), they saw more benefit in hands-on training.

Many of the controllers thought voice communication is very natural to the current controllers, who would not have any problem in reverting to voice communication when Data Comm would fail. They worried less about their own training on Data Comm but more about new controllers who would start with Data Comm. Their concern was that the new controllers might have a hard time reverting to voice communication when Data Comm would fail.

4. DISCUSSION

First, we will discuss the experimental results under each of the research questions. Second, we will discuss where these results would lead us. Finally, we will present recommendations for the future Data Comm.

4.1 Human-Machine Interface

Following the HMI training and testing with Keyboard, Graphical, and Template input modes, the participants used the combined HMI. Although we found a difference in the number of PTT events among the four HMI implementations, the differences were small. The only HMI pair that was significantly different consisted of the template and Combined modes. The workload ratings, questionnaire data, and debriefing comments also indicated that the use of a template as the sole input mechanism for Data Comm messages will have a negative impact on the ATC tasks. The participants considered the Combined mode most helpful. When we examined the participants' questionnaire ratings on ATC and communication tasks, we also found a significant difference between these two modes on some of the tasks. Thus, it was clear that the Combined mode was the best HMI, but the degree of its superiority to the Template mode depended on the tasks that they performed. The main complaint against the template was that it took controllers too long to accomplish a task with it, that it occupied too much space, and that it was too cumbersome to use. Based on these data, we had expected that changes in oxygenation as an indicator of cognitive workload would be highest for the Template condition. The objective oxygenation data did not support that assumption. Although the results did not reach statistical significance, the data showed lower oxygenation levels for the keyboard than for the other modes. The keyboard condition represents the most familiar environment with an accompanying low level of conscious effort. The effect of expertise may explain the trend in lower oxygenation levels for the keyboard condition. The time and distance data that measured the efficiency of air traffic control did not show any difference between HMI modes. It is plausible that the objective data we used might not have been sensitive enough to reveal the differences between the HMI modes.

When we used aircraft maneuvers to examine the HMI usage, we found the participants' various usage patterns. The participants preferred using a particular communication method over the other method and a certain HMI mode over other HMI modes for certain tasks. For instance, controllers preferred to issue altitude clearances by data communications in all HMI configurations. In our simulation, the participants could uplink all NAS updates using Data Comm as in the current ERAM system. Controllers could issue altitude clearances using flyout menus from the data block, or by keyboard entry, in all HMI configurations in the Data Comm condition. In addition, they could save it as a sequence of keyboard entries as a macro for later use.

Another favored combination of a communication method and a HMI mode was that controllers preferred to issue crossing clearances by data communications when they used the Keyboard or Combined, but strongly preferred voice communications when they used the Template. Controllers preferred voice communications to issue crossing clearances when they used the Graphical. In our simulation there were specific ways to issue the crossing clearances. That is, in the Template HMI scenario, controllers could only uplink a crossing clearance by using the Template itself. In the Graphic HMI mode, the participants must enter crossing restriction by displaying the route and using FOM from the 4-D Trajectory Data Block (the 4DB). In the Keyboard HMI scenario, the participants must type in, although once entered, a specific restriction could be saved as a macro. In the Combined HMI scenario, all these methods were available.

In the Graphical and Combined HMI conditions, controllers could issue clearances using an interactive trajectory. They could modify the displayed trajectory through either rerouting an aircraft, providing crossing restrictions, or initiating maneuvers at a point in space or time along the trajectory. Consequently, controllers displayed more routes in the Graphical conditions. The data also showed that the R-side controllers used this capability more often than the D-side controllers, but the difference was not statistically significant.

We examined which mode was more prone to entry errors. Keyboard entries were more prone to entry errors because there were more chances to mistype a value or a computer identification of aircraft. During the graphical and template conditions, we tied off advanced keyboard-based Data Comm capabilities such as keyboard shortcuts in macros. Our results indicated that controllers had stored and used these using macros but they could not use them under the Graphical and Template conditions.

When controllers were working with the graphical and combined HMI options, they used fewer flight-plan readouts. This complements our finding that they used more graphical route displays. It seems that the use of a graphical route display provides controllers with some information that they could have received from the flight-plan readout.

Among the four HMI modes, our results of workload ratings and comments showed that the combined mode was the preferred input mode because it was flexible and powerful, and it had all the functionality of keyboard, template, and graphical modes. The template mode, as we implemented it in the simulation, was not favored at all. The participants commented that it was too cumbersome to use and took too much time to type in information. We do not recommend the template mode for the Data Comm.

4.2 Equipage

We found that pilots had more PTT events than controllers had. One reason for this finding may be that pilots more likely aborted a voice call and tried to call again when another pilot or a controller stepped on a transmission. Another potential reason may be that our simulation pilots tend to break up a voice communication event into more than one PTT events (i.e., the pilots sometimes release the microphone within a single utterance). This would then have resulted in shorter PTT events for pilots than for controllers, but our analysis of the duration of PTT events indicated that the duration did not change as a function of equipage level or actor. Thus, with the data we analyzed so far, we do not know the cause of the significant higher pilots PTTs over controllers PTTs.

During the introduction and training, we emphasized that controllers should use voice communications in tactical situations. Because the traffic scenarios were identical (except call signs) across conditions, we expected that in tactical situations, their use of verbal communication between the 100% equipage level and other equipage levels would be the same. However, we found the number of the PTTs in the 100% level conditions in tactical situations was quite low. We suspect that controllers might have changed their control strategy in a way that fewer tactical situations occurred or that controllers used Data Comm even in tactical situations that should have required voice communications. Of the few cases of a loss of separation we found two situations where controllers used data communications in a tactical situation, suggesting that the latter situation occurred at least sometimes.

Our PTT data showed no difference between 0% and 10% equipage levels. However, there were significant differences between them and 50% and between them and 100%. There was no difference between 50% and 100% levels. The workload data showed the same results. The questionnaire rating data showed similar results. As we mentioned, the controllers rated the Data Comm interface after each experimental run on how it affected their ATC and communication. Overall, for the six ATC tasks (situation monitoring, resolving aircraft conflict, managing aircraft conflict, rerouting or planning flights, and managing sector position resources), the R-side controllers consistently responded that the Data Comm interface with the 100% equipage level was most helpful. They also responded that the 100% level was more helpful than the 50% level in all the tasks except the task of situation monitoring. The D-side controllers also rated the 100% level as more helpful than other equipage levels in all six tasks, but only two tasks (routing or planning flights and managing sector/position resources) showed statistical significance. Only one task, the task of managing sector/position resources, showed statistical difference between the 100% and 50% levels. Thus, the equipage level was not a big factor for the D-side controllers.

The R-side controllers' rating of the second part questionnaire also showed the superiority of the 100% level in a few tasks. The difference between the 100% and 50% levels was significant in one task (current route modification) only, however. The D-side ratings on this second part questionnaire did not show any significant differences among different equipage levels, except the difference between 50% and 0% equipage levels for the task of crossing constraint at a specified altitude. As was the case with the first part questionnaire, the equipage levels did not hinder or help D-side controllers in any of the ATC communication tasks. It is not clear with the current data why the Data Comm equipage levels did not matter much to the D-side.

The total number of maneuver clearances increased with increasing level of Data Comm equipage. Route clearances showed the greatest increase, and eastbound flights accounted for much of that. Eastbound flights were flying into clear weather, so we presume that controllers mostly re-routed them to increase efficiency. Controllers issue these clearances as their workload permits. We provisionally conclude that controllers working in the 100%-Data Comm condition had sufficient time after completing their essential tasks to issue more nonrequired clearances.

Even in the busy voice-only scenario, controllers completed all essential tasks; in particular, routing westbound aircraft around the weather. The weather system constrained westbound flights so that additional re-routes for efficiency were generally not feasible. Therefore the number of re-routes of westbound flights did not vary significantly across equipage levels.

Contrary to our expectations, we found that the 0% equipage or voice-only condition resulted in the lowest oxygenation increase. The part-task experiment conducted as part of the project has shown that for 10-minute ATC vignettes with 6, 12, and 18 aircraft a voice-only environment resulted in a higher oxygenation increase than a Data Comm only environment (Izzetoglu, Bunce, Shewokis, & Ayaz, 2010). The results from the part-task experiment showed an average oxygenation increase of approximately 0.2 for the voice-only condition for Voxel 8 (see Figure 69). Voxel 8 activity during the main experiment showed a reduction in oxygenation for the voice-only condition and higher oxygenation levels during scenarios that contained Data Comm equipped aircraft.

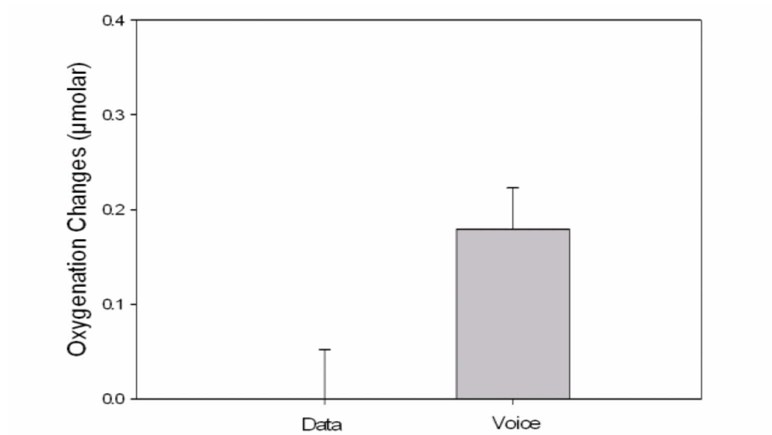


Figure 69. Average oxygenation changes at Voxel 8 for Data Comm and Voice Comm (N = 22). Error bars are SEM (adapted from Izzetoglu, Bunce, Shewokis, & Ayaz, 2010).

In the part-task experiment, all controllers worked traffic as a single R-side controller. They either worked under a condition where only voice communication was available or under a condition where only data communication was available. Thus, in the part-task environment, the controllers did not have the option whether to use voice communication or data communication when they were in the Data Comm-only condition. In the main experiment, they could use either voice or data communication in the Data Comm conditions. The voice-only environment had the least amount of uncertainty about which modality to use for communications with the aircraft. That uncertainty increased with an increasing percentage of aircraft equipped with Data Comm. The oxygenation data indicate that there is an associated increase in cognitive processing. At 100% Data Comm equipped aircraft, controllers always have data communications and voice available, thereby reducing the uncertainty but still needing to decide if the use of data communications is the appropriate modality to use in a particular situation. We see a reduction in cognitive activity, but it does not come down to the levels that we saw for voice-only conditions.

The subjective workload data we collected from controllers do not correspond with the objective fNIR data. One possible explanation is that the oxygenation data may access cognitive, nonautomatic processing. In the most familiar environment for expert controllers, there may be less effortful cognitive processing, resulting in less of a change in oxygenation levels. The data communications capabilities are new to the controllers and may result in more nonautomated processing in the brain despite the fact that controllers feel that it reduces their workload. If we would follow a cohort of controllers that make data communications services as much second nature as voice communications is today, we may see that the differences in cognitive activity will reduce over time.

Our results show that controllers aborted fewer entries with increasing levels of equipped aircraft. The R-side also made fewer erroneous entries with increasing levels of equipped aircraft. This may be an indication of more frequent use of display interactions to make data entries instead of relying on the keyboard. When using the keyboard to make entries, controllers often want to ensure that the MCA is clear of incomplete entries and use a dedicated CLEAR key or ENTER to remove anything left over from previous interactions.

We also found more undefined entries with increasing equipage levels. Undefined entries are correct entries, as far as the NAS grammar format, but do not result in a change in the NAS.

Although the statistical analyses were not significant, our results hint at a division of tasks between the R-side and D-side in terms of keeping the display free of clutter. We found indications that the R-side controller drops data blocks (from an FDB to an ADB and from an ADB to a correlated LDB). This is somewhat counterintuitive because we have assumed that the D-side controller would still have a supporting role and would assist the R-side controller in removing clutter from the display. Our data suggests that the tactical R-side controller takes care of this more often than the D-side controller. Equipage level did affect the number of times controllers moved data blocks (as memory joggers or to reduce clutter) and this is most likely related to the increase in the use of macros with increasing equipage levels. Some macros that controllers created contained data block movements as memory joggers.

We found a clear increase in the use of macros with an increase in equipage levels. Most of the macros contained only few controller entries, but combined Data Comm as well as NAS and display entries. In this experiment, we had no restriction of how controllers could combine data entries. So, controllers could send an aircraft an altitude restriction via data communications and handoff the aircraft to the next sector. The implementation of data communications services may have more restrictions on the combinations of data entries a macro may contain. Controllers also frequently used macros to release a transfer of communications and offset a data block to remind them that they had instructed the aircraft to switch its frequency to the next sector.

Based on the subjective data, including questionnaire ratings, workload rating, and comments, it was clear that the participants favored the higher Data Comm equipage levels. They could take advantage of Data Comm capabilities, such as 4-D trajectory displays, and appreciate the convenience of graphical interface when they rerouted aircraft. Because they were not tied up on the verbal communication with the pilots, they had more time to coordinate with the other controllers verbally. An efficiency measure defined by time and distance of aircraft flown while in the sector also showed that controllers directed aircraft more efficiently when all aircraft were Data Comm equipped. Since this effect was significant only for the data when aircraft were under the frequency control, this result is not strong. Nevertheless, we can confidently conclude that controllers took advantage of the Data Comm capability when a higher proportion of the aircraft, such as 50% and especially 100%, were Data Comm equipped. The low 10% equipage level did not help controllers.

4.3 Failure

We divided the participants into two groups: one group experienced partial Data Comm failure and the other group experienced a system-wide outage. Some controllers said that during a partial failure mode, they reverted to voice for all aircraft. Our PTT data did not support this comment. Our data suggests that in general, controllers reverted to voice communication for the aircraft that had lost Data Comm, but we found no indication that additional voice communication took place for other aircraft.

Workload ratings were not significantly higher for the scenario that had individual aircraft data-communication failures than the control scenario without failures. In the scenarios that had individual aircraft failures, six aircraft failed during the 50-minute test scenario, between 5 and 9 minute intervals. At any given time, therefore, there were likely one or two *failed* aircraft in the sector. To the extent that verbal clearances would increase workload, workload would fluctuate even in the absence of failures, as aircraft entered and left the sector. This effect and any additional effect related to the individual aircraft failures were not large enough to be statistically significant.

In the system-wide failure mode, the PTT data showed a significant increase from the other failure modes (partial, individual aircraft, and no failure modes). The data did not show the difference between the partial and individual aircraft failure modes. The questionnaire data showed that both partial and system failure modes were more detrimental than individual aircraft failure. In addition, the system failure mode was more detrimental than the partial failure mode. Our challenge is to design a Data Comm system that would be still helpful to controllers during partial and system-wide failures. As our controllers suggested, we may need to make the failure symbols more salient and create an effective training program for the different types of Data Comm failures.

We had three types of Data Comm failure modes. Because the participants preferred Data Comm, they rated that traffic control was more difficult when higher level failures, such as partial and total system failures, occurred. They also commented that sometimes the various symbols of Data Comm status were not pronounced enough to attract their attention on time. We would need more distinct and pronounced symbols for various Data Comm statuses. A training program for the procedure and phraseology to use when a failure occurs is very important.

4.4 Flight Management System Integration

We simulated nonintegrated FMS systems, by increasing the delay of the aircraft responding to an uplinked message to the point where time-outs were more likely. This could add tasks for controllers because they would spend more time monitoring the status of messages, resending messages after a time-out, or planning a new tactical control action due to the pilot's failure to execute a clearance in a timely manner. As we expected, controllers reported lower workload when all Data Comm aircraft in their sector had integrated FMS than when only half of the Data Comm aircraft had integrated systems.

4.5 Service Policy

Workload ratings data showed that any effort that controllers had attempted to apply the BEBS policy was not significant. The controllers mentioned during the debriefings that a BEBS policy did not affect their performance in the current experiment. They did believe, however, that mandating equipage in certain pieces of airspace or routes would be a more natural way to implement a BEBS procedure.

The fNIR results showed that BEBS conditions did not affect cognitive activity as indicated by changes in oxygenation of the brain. During BEBS conditions, we instructed controllers to provide preferential treatment to aircraft that had data communications capabilities when operationally feasible. Although we provided examples of what types of situations would lend itself to preferential treatment, we did not force controllers to use preferential treatment. The instructions to provide BEBS did not affect the level of cognitive processing in our participants. This may be an indication that controllers were not providing BEBS. Alternatively it may be an indication that providing BEBS does not alter the way controllers are controlling traffic enough to cause a change in cognitive activity. Controllers indicate that without procedures that tell them exactly what to do to provide preferential treatment, operational benefits will govern their actions. So, if it is easier to move an aircraft by sending a data communications message than by providing a voice clearance, the controller is more likely to move the equipped aircraft.

Controllers have no feedback that helps them decide if a maneuver provided a benefit to an aircraft. For example, if a controller gives an aircraft preferential treatment and sends an aircraft direct to a fix, saving the aircraft time in the sector, but as a result the aircraft no longer flies its most fuel-efficient trajectory this may not be the preferred solution for the airline. The controller currently has no way of knowing.

4.6 End-to-End Technical Delays

Because the technical delays will not change between Data Comm Segment 1 and Segment 2, we introduced a difference in round-trip delay by reducing the pilot response time for Segment 2. The participants did not notice that we had a scenario that had reduced round-trip delays.

4.7 Roles and Responsibilities

One concern he have is that the change in experimental conditions would change the distribution of eye-movement fixations and their duration. Our initial analysis does not show an effect of our experimental conditions on the fixations in general or dwells on aircraft. This finding suggests that at a macroscopic level, our concern was unwarranted. From an interface design viewpoint, however, we still have a concern that at a microscopic level, the increased use of graphical interaction with the system will lock the visual system onto the interaction instead of distributing the visual scan across the traffic representation.

We found that the fixation durations were, on average, longer than durations we have found in other studies. Further analysis of the available data will need to explore what may have caused this change in fixation durations. An increase in fixation durations results in fewer fixations per unit of time and, therefore, in visits to fewer objects. The visual scan provides the main source of data that the controller has available to maintain situation awareness. Therefore, our data seems to indicate that the ability to maintain situation awareness may have been different from data in earlier studies.

One of the questions that the Data Comm Program Office had early on in the preparation for this experiment was how the introduction of Data Comm may affect roles and responsibilities. To determine whether controllers changed the way they collaborated, we looked at the distribution of the visual scan between a controller's own display and that of the other controller's display. In this experiment, the distributions did not change, but there is an interesting observation that one cannot derive from a statistical analysis of the data but from a comparison with current controller activities. We found that the controllers were hardly ever looking at the other controller's display.

In this experiment, we provided the R-side and the D-side controllers with identical displays, with identical capabilities. The eye movement data suggest that controllers worked by assessing the visual data independently. This is quite different from current operations in which the D-side controller does not have a surveillance display and has to rely on the R-side display to assist in surveillance-based separation and to receive feedback on actions that include feedback on the display (e.g., route amendments, separation of data blocks, accepting handoffs). This finding does not mean that the controllers do not collaborate. Our observations suggest that with less voice air/ground communications there is more communication between team members, but further analysis of the off-frequency communications between controllers will need to illuminate how intra-team communications may have changed. To investigate a change in intra-team communications, one could use the taxonomy proposed by Peterson, Bailey, and Willems (2001).

The reason that we included controller position as an independent variable in many of our analysis was that a shift in roles and responsibilities might occur with certain levels of Data Comm equipage, HMI mode changes, or traffic control procedure changes. In the oxygenation data, we found a difference between the D-side and the R-side that we did not expect. After all, we provided the R- and D-side controllers with identical displays and with identical capabilities. We also did not specify any new role and responsibility changes for the R- and D-side controllers. The data showed that oxygenation changes were higher for the D-side controllers at some voxels. If the difference was present, it tended to persist across experimental conditions. We suspect that the D-side controllers might not have been clear about their responsibilities and as a result their work during the simulation demanded more effort.

4.8 General Discussion

The controllers welcomed Data Comm as a flexible and powerful tool. They commented that they could handle more traffic with the Data Comm system than with voice communications. Because air traffic control is complex and time critical, they preferred the most flexible HMI mode, the Combined mode. The controllers preferred not to use the Template mode because it was cumbersome and time-consuming.

The controllers did not perceive that the 10% equipage level was helpful to them. Our results showed that the significant contribution of Data Comm occurred at the equipage levels of 50% and 100%. However, most of the participants agreed that the higher equipage levels changed the way that they controlled traffic, especially when all aircraft were Data Comm equipped; it presented a new work environment that they had never encountered. They mentioned that the R- and D-sides seemed to work much more independently and that the D-side had difficulty in helping the R-side. To increase coordination and cooperation between R- and D-sides in the Data Comm system, we may need to add explicit symbols or features on the display that would show what tasks the other controller is performing. We may need to establish new roles and responsibilities for R- and D-sides.

Although the controllers mentioned that they had not changed their control strategy at high Data Comm equipage levels, they did not issue many tactical voice clearances during the 100% equipage condition. Incidentally, the different equipage levels did not hinder or help D-side controllers at all according to their responses in the questionnaire. It is not clear with the current data why the equipage levels did not matter much to the D-side. We conjecture that the D-side did not fully take advantage because of the currently established R- and D-side roles and responsibilities.

Data Comm failures by an individual aircraft did not have a noticeably negative effect. Partial and system-wide failures did. As our controllers suggested, we may need to make the failure symbol more salient and give an effective training program to controllers for the different types of failures. Data Comm would help controllers plan ahead in issuing clearances, sequencing aircraft, and distributing their resources. This will ease some of their activities, but it will also add new tasks and force them to change their ways of controlling air traffic. Our experimental results and concerns expressed in this paper will help the FAA design an efficient Data Comm system and a training program.

Controllers identify aircraft, issue clearances, monitor air traffic situations, resolve aircraft conflicts, manage air traffic sequences, route or plan flights, assess weather impact, and manage sector/position resources (Alexander, Alley, Ammerman, Hostetler & Jones, 1988). They perform these tasks sequentially or simultaneously depending on the tasks on hand. The introduction of Data Comm provides controllers with additional options to execute these tasks. Data Comm provides relief for some controller activities, but it also adds new tasks and will change the way controllers operate. On the basis of the available data, we find that Data Comm lowered controller workload. However, our questionnaire data showed that it helped controllers with some tasks more than others.

In general, controllers' subjective ratings of workload using the WAK keypad were rather low, considering that we set the traffic level to approximate 150% of the current MAP level, estimated by our SMEs. In addition, the range of ratings given by controllers in a team tended to be narrow (the center of the range varied from team to team, however).

The narrow range of workload ratings that controllers used tends to reduce differences between average ratings under different experimental treatments. Nevertheless, we found statistically significant differences between the Template and Combined HMIs and between low and high percentages of Data Comm equipage.

5. RECOMMENDATIONS

5.1 General Recommendations

- **Use spiral implementation of data communications services.** The participants indicated that data communications training could be brief for the most frequently used clearances, but require much more time for the full message set. Our data also shows that controllers used only a few messages frequently. Therefore the biggest return in a reduction in workload and voice congestion will come from providing support for these messages.

- **Determine the amount of time it takes before controllers have made Data Comm symbology, procedures, and capabilities part of their routine control behaviors.**
- **Determine more realistic pilot response times to different clearance types.**
- **Conduct follow-on research that determines acceptable response times for specific message types.**
- **Provide visual feedback for the status of voice-based clearances.** Unlike the detailed feedback provided for Data Comm entries, there is currently no indication that a NAS entry corresponds to a voice-based clearance.
- **Provide immediate feedback in the track area when a Data Comm entry failed.** We provided feedback in a separate view, but controllers indicated that this was not salient enough.
- **Revisit and standardize Data Comm symbology.**
- **Provide improved feedback across sector positions.** The participants indicated that they were less aware of the other controller's activities, because data communications clearances are silent.
- **Determine if the automation can incorporate expected data communications delays in alerts and advisories to advise controllers when to use voice instead of data communications.** Examples of automation include conflict alert, conflict probe, and time-based metering systems.

5.2 Human-Machine Interface

- **Provide keyboard and graphical user interface options to controllers to make Data Comm entries.** Our data suggest that a template-driven entry method will go unused.
- This study focused on integration of data communications capabilities within the situation display, conflict probe, and other existing display elements. **Future studies need to address integration of data communications capabilities with new automation functions such as assisted metering maneuvers, conflict resolution advisories, traffic flow initiatives, and weather advisories.**
- **Provide more macros than the current ERAM limit.** With an increase in data communications equipped aircraft, controllers will rely more heavily on a larger number of macros.
- **Integrate data communications capabilities in the track area of the situation display when possible.** Additional views and displays for incoming, outgoing, and archival messages were available in this study, but controllers did not use them.

5.3 Equipage Levels

- Increasing levels of data communications equipped aircraft will reduce or even eliminate voice communications and reduce subjective workload. The presence of aircraft that controllers can address via voice as well as via data communications may increase cognitive effort.

  - **Provide adequate training to incorporate data communications in the controller's day-to-day operations.**
  - **Provide training to teach controllers to recognize situations where the use of data communications is not appropriate**, such as tactical situations.
- **Determine the equipage level at which reduction of workload and voice congestion become significant.**

5.4 Best-Equipped, Best-Served

- **Provide automation support to assist controllers in the implementation of Best-Equipped, Best-Served policies**. If left to the controllers, they will not control traffic with an incentive for airspace users to further equip in mind, but instead look at the operational benefit. Controllers indicated that automation support could incorporate these policies relieving the burden of assigning priorities.

5.5 Flight Management System Integration

- **Determine more realistic pilot response times that differentiate between integrated and nonintegrated FMS.**
- **Conduct air/ground integration studies that include realistic flight deck procedures to establish anticipated pilot response times in domestic airspace.**

5.6 Data Communication Failures

- In the current experiment, controllers had no immediate feedback other than a change in the view that shows status of radar, data communications, and other equipment. Our controllers suggested to **provide more immediate feedback about aircraft affected by data communications failures.**
- **Conduct follow-on research that investigates how to support controllers during the transition into and from a data communications failure.**

5.7 Round-Trip Delay Times

- Controllers did not notice the reduction in delay times we had provided. **Further research should define what acceptable maximum delay times are.**

5.8 Roles and Responsibilities

- **Establish procedures to formalize intra-team coordination and responsibilities when using data communications services.**
- **Provide tools to use the sector displays to support intra-team communications.** Our study shows that controllers worked more independently when the R-side and D-side had Data Comm available and used identical workstations. We need to provide them opportunities to maintain team situation awareness.
- **Conduct Human-in-the-Loop studies that force controllers to provide all types of advisories required in an operational environment.** These advisories should include at least weather advisories, NOTAMs, and sector-to-sector advisories such as point-outs and coordination.

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Acronyms

ACARS	Aircraft Communications and Reporting System
ADB	Area of interest Data Block
ANOVA	Analysis of Variance
ARTCC	Air Route Traffic Control Center
ATC	Air Traffic Control
ATOP	Advanced Technologies and Oceanic Procedures
ATWIT	Air Traffic Workload Input Technique
BEBS	Best equipped, Best served
CPC	Certified Professional Controller
CPDLC	Controller-Pilot Data Link Communications
CRD	Computer Readout Device
Data Comm	Data Communications
DESIREE	Distributed Environment for Simulation, Rapid Engineering, and Experimentation
D-side	Data-side
DSR	Display System Replacement
ERAM	En Route Automation Modernization
FAA	Federal Aviation Administration
FCFS	First-come, First-served
FDB	Full Data Block
FEWS	Future En Route Workstation
FLAT	Flight Plan Assisted Tracking
FMS	Flight Management System
fNIR	Functional Near Infrared
FOM	Fly-Out Menu
HITL	Human-In-The-Loop
HMI	Human-Machine Interface
HPA	High Performance Airspace
JPDO	Joint Planning and Development Office
KSD	Keypad Selection Device
LDB	Limited Data Block
LED	Light Emitting Diode
LOA	Letter of Agreement

MAP	Monitor Alert Parameter
MCA	Message Composition Area
NAS	National Airspace System
NextGen	Next Generation Air Transportation System
NOTAM	Notice to Airmen
ORF	Observer Rating Form
OTS	Over-The-Shoulder
POG	Point of Gaze
PSQ	Post-Scenario Questionnaire
PTT	Push-To-Talk
RDHFL	Research Development and Human Factors Laboratory
R-side	Radar-side
RTCA	Radio Technical Commission for Aeronautics
SME	Subject Matter Expert
SOP	Standard Operating Procedure
STA	Scheduled Time of Arrival
TBO	Trajectory-Based Operations
TDB	Trajectory Data Block
TGF	Target Generation Facility
TMA	Traffic Management Advisor
TOC	Transfer of Communications
VSCS	Voice Switching and Control System
WAK	Workload Assessment Keypad
WJHTC	William J. Hughes Technical Center

Appendix A

Data Communications Segment 1 Message Set

DATA COMMUNICATIONS SEGMENT 1 MESSAGE SET

Msg #	Message Description	HITL*
	Uplink Messages	
	Response/Acknowledgment	
0	UNABLE	Y
1	STANDBY	Y
3	ROGER	Y
4	AFFIRM	Y
5	NEGATIVE	Y
211	REQUEST FORWARDED	N
237	REQUEST AGAIN WITH NEXT UNIT	N
	Vertical Clearance Messages	
6	EXPECT (level)	Y
19	MAINTAIN (level)	Y
20	CLIMB TO (level)	Y
21	AT (time) CLIMB TO (level)	Y
22	AT (position) CLIMB TO (level)	Y
23	DESCEND TO (level)	Y
24	AT (time) DESCEND TO (level)	Y
25	AT (position) DESCEND TO (level)	Y
26	CLIMB TO REACH (level) BY (time)	Y
27	CLIMB TO REACH (level) BY (position)	N
28	DESCEND TO REACH (level) BY (time)	Y
29	DESCEND TO REACH (level) BY (position)	N
171	CLIMB AT (vertical rate) MINIMUM	N
172	CLIMB AT (vertical rate) MAXIMUM	N
173	DESCEND AT (vertical rate) MINIMUM	N
174	DESCEND AT (vertical rate) MAXIMUM	N
	Crossing Constraint Messages	
46	CROSS (position) AT (level)	Y
47	CROSS (position) AT OR ABOVE (level)	Y
48	CROSS (position) AT OR BELOW (level)	Y
49	CROSS (position) AT AND MAINTAIN (level)	Y
50	CROSS (position) BETWEEN (level) AND (level)	N
51	CROSS (position) AT (time)	Y
52	CROSS (position) AT OR BEFORE (time)	Y
53	CROSS (position) AT OR AFTER (time)	Y
54	CROSS (position) BETWEEN (time) AND (time)	Y
55	CROSS (position) AT (speed)	Y
58	CROSS (position) AT (time) AT (level)	Y
59	CROSS (position) AT OR BEFORE (time) AT (level)	Y
60	CROSS (position) AT OR AFTER (time) AT (level)	Y

Msg #	Message Description	HITL*
61	CROSS (position) AT AND MAINTAIN (level) AT (speed)	Y
62	AT (time) CROSS (position) AT AND MAINTAIN (level)	Y
63	AT (time) CROSS (position) AT AND MAINTAIN (level) AT (speed)	Y
	Lateral Offset Messages	
64	OFFSET (specified distance) (direction) OF ROUTE	Y
72	RESUME OWN NAVIGATION	Y
	Route Modification Messages	
73	(departure clearance)	N
74	PROCEED DIRECT TO (position)	Y
79	CLEARED TO (position) VIA (route clearance)	Y
80	CLEARED (route clearance)	Y
82	CLEARED TO DEVIATE UP TO (specified distance) (direction) OF ROUTE	N
83	AT (position) CLEARED (route clearance)	Y
84	AT (position) CLEARED (procedure name)	Y
92	HOLD AT (position) AS PUBLISHED MAINTAIN (level)	Y
94	TURN (direction) HEADING (degrees)	Y
215	TURN (direction) (degrees)	Y
190	FLY HEADING (degrees)	Y
96	CONTINUE PRESENT HEADING	Y
99	EXPECT (procedure name)	N
	Speed Change Messages	
106	MAINTAIN (speed)	Y
107	MAINTAIN PRESENT SPEED	Y
108	MAINTAIN (speed) OR GREATER	Y
109	MAINTAIN (speed) OR LESS	Y
116	RESUME NORMAL SPEED	Y
222	NO SPEED RESTRICTION	Y
	Contact/Monitor/Surveillance Messages	
117	CONTACT (unit name) (frequency)	Y
120	MONITOR (unit name) (frequency)	Y
123	SQUAWK (code)	Y
179	SQUAWK IDENT	Y
	Report/Confirmation/Request Messages	
133	REPORT PRESENT LEVEL	Y
135	CONFIRM ASSIGNED LEVEL	Y
231	STATE PREFERRED LEVEL	Y
232	STATE TOP OF DESCENT	Y

Msg #	Message Description	HITL*
	Negotiation Request Messages	
148	WHEN CAN YOU ACCEPT (level)	Y
	System Management Messages	
213	(facility designation) ALTIMETER (altimeter)	
157	CHECK STUCK MICROPHONE (frequency)	Y
159	ERROR (error information)	Y
160	NEXT DATA AUTHORITY (facility)	
162	SERVICE UNAVAILABLE	N
227	LOGICAL ACKNOWLEDGMENT	N
233	USE OF LOGICAL ACKNOWLEDGMENT PROHIBITED	N
	Additional Messages	
165	THEN	N
183	(free text - no reply)	Y
196	(free text - WILCO/UNABLE)	
203	(free text - ROGER)	
205	(free text - AFFIRM/NEGATIVE)	

Downlink Messages

Msg #	Message Description	HITL*
	Responses	
0	WILCO	Y
1	UNABLE	Y
2	STANDBY	Y
3	ROGER	Y
4	AFFIRM	Y
5	NEGATIVE	Y
	Vertical Request Messages	
6	REQUEST (level)	Y
9	REQUEST CLIMB TO (level)	Y
10	REQUEST DESCENT TO (level)	Y
	Speed Request Messages	
18	REQUEST (speed)	Y
	Route Modification Messages	
22	REQUEST DIRECT TO (position)	Y
23	REQUEST (procedure name)	Y
24	REQUEST CLEARANCE (route clearance)	Y
25	REQUEST (clearance type) CLEARANCE	N
27	REQUEST WEATHER DEVIATION UP TO (specified distance) (direction) OF ROUTE	N

Msg #	Message Description	HITL*
	Reports	
32	PRESENT LEVEL (level)	Y
37	MAINTAINING (level)	Y
38	ASSIGNED LEVEL (level)	Y
79	ATIS (ATIS code)	Y
89	MONITORING (unit name) (frequency)	
106	PREFERRED LEVEL (level)	Y
109	TOP OF DESCENT (time)	Y
	System Management Messages	
62	ERROR (error information)	Y
63	NOT CURRENT DATA AUTHORITY	N
99	CURRENT DATA AUTHORITY	N
107	NOT AUTHORIZED NEXT DATA AUTHORITY	N
100	LOGICAL ACKNOWLEDGMENT	N
	Additional Messages	
65	DUE TO WEATHER	N
66	DUE TO AIRCRAFT PERFORMANCE	N
67	(free text - LOW alert)	N
98	(free text - no alert)	N
	Negotiation Request Messages	
81	WE CAN ACCEPT (level) AT (time)	Y
82	WE CANNOT ACCEPT (level)	Y

*Unless indicated by “N,” the message will be enabled in the HITL simulation on the DESIREE platform.

Appendix B

Informed Consent Statement

INFORMED CONSENT STATEMENT

I, ______________________________, understand that this simulation, entitled "En Route Data Communications" is sponsored by the Federal Aviation Administration (FAA) and is being directed by Mr. Ben Willems.

Nature and Purpose:
I volunteered as a participant in this simulation. The primary purpose of the simulation is to validate and elicit requirements for pilot/controller data communications systems. The simulation will evaluate these concepts in high traffic scenarios under optimal and suboptimal (e.g., weather) conditions using a simulated En Route Automation Modernization (ERAM) system. The results of the study will be used to determine the benefits and feasibility of implementing these procedures and interface components.

Experimental Procedures:
Twenty-four en route Certified Professional Controllers will participate for 6 days. Two teams of two participants will work simultaneously but independently. Each team will consist of one R-side controller and one D-side controller to manage complex training and test scenarios using each condition. The participants will work from about 8 AM to about 4 PM every day with a lunch break and at least two rest breaks. The first morning will consist of an inbriefing to review project objectives and participant rights and responsibilities, and will include initial familiarization training on the airspace, systems, and procedures. The participants will then begin training for a on scenarios that are up to 30-minutes long. After training is completed on one system, the participants will complete 50-minute test scenarios using that system. The order of the systems and the test scenarios will be counterbalanced. On the final day, the participants will gather for a final debriefing session to provide feedback on the systems and procedures. During the some of the training scenarios and all of the test scenarios, the participants will wear a head-mounted oculometer to record eye movement data. They will also respond to workload prompts at designated intervals throughout each scenario. In addition, the Subject Matter Experts will record observations about each scenario. An automated data collection system will record system operations and generate a set of standard Air Traffic Control (ATC) simulation measures, including safety, capacity, efficiency, and communications. After each scenario, the participants will complete questionnaires to report their overall workload, situation awareness, and performance and to provide an assessment of the system and test condition. The simulation will be audio and video recorded. At the end of the experiment, they will fill out an exit questionnaire and receive a debriefing about the experiment.

Anonymity and Confidentiality:
My participation is strictly confidential. Any information I provide will remain anonymous: no individual names or identities will be associated with the data or released in any reports.

Benefits:
I understand that the only benefit to me is that I will be able to provide the researchers with valuable feedback and insight into the effects of emerging ATC concepts and alternative workstation interface designs for use in en route airspace. My data will help the FAA to establish the benefits and feasibility of these procedures within this environment.

Participant Responsibilities:
I am aware that to participate in this study I must be a certified professional controller who is qualified at my facility and holds a current medical certificate. I must also have normal or

corrected-to-normal (20/20) vision. If I am selected to wear the eye-tracking device, I cannot wear bifocals, trifocals, or hard-contact lenses that are incompatible with it. I will control traffic and answer questions asked during the study to the best of my abilities. I will not discuss the content of the experiment with other potential participants until the study is completed.

Participant Assurances:
I understand that my participation in this study is voluntary and I can withdraw at any time without penalty. I also understand that the researchers in this study may terminate my participation if they believe this to be in my best interest. I understand that if new findings develop during the course of this research that may relate to my decision to continue participation, I will be informed. I have not given up any of my legal rights or released any individual or institution from liability for negligence.

The research team has adequately answered all the questions I have asked about this study, my participation, and the procedures involved. I understand that Mr. Willems or another member of the research team will be available to answer any questions concerning procedures throughout this study. If I have questions about this study or need to report any adverse effects from the research procedures, I will contact Mr. Willems at (609) 485-4191.

Discomfort and Risks:
I understand that traffic levels may become higher than I can effectively manage. I understand that this will not reflect on my career or performance as an air traffic controller.

The device that monitors eye movements may cause some discomfort. The skin area under the headband that supports the device may show some redness after wearing the device for the duration of the scenario. The intensity of the infrared beam that illuminates the eye is about one thirtieth of the intensity expected while walking outside on a sunny day and should not cause any discomfort or risk to my health.

A silicon pad containing small light emitting diodes (LEDs) and light detectors will be placed over the participant's forehead with a headband. Low power light will be shown onto the area of interest during the testing period, and changes in the amount of light that returns to the sensor will be used to calculate underlying changes in the concentrations of oxygenated and deoxygenated hemoglobin.

The risks associated with a protocol utilizing fNIR are less than the risks associated with spending an equivalent amount of time in the sunlight in the United States without a hat.

I agree to immediately report any injury or suspected adverse effect to Mr. B. Willems at (609) 485-4191. Local clinics and hospitals will provide any treatment, if necessary. I agree to provide, if requested, copies of all insurance and medical records arising from any such care for injuries/medical problems.

Signature Lines:
I have read this informed consent form. I understand its contents, and I freely consent to participate in this study under the conditions described. I understand that, if I want to, I may have a copy of this form.

Research Participant:____ Date:__________

Investigator:____ Date:__________

Witness:____ Date:__________

Appendix C

Biographical Questionnaire

BIOGRAPHICAL QUESTIONNAIRE

Date:

Participant:

Instructions:

This questionnaire is designed to obtain information about your background and experience as a certified professional controller (CPC). Researchers will only use this information to describe the participants in this study as a group. Your identity will remain anonymous.

Demographic Information and Experience

1. What is your **gender**?	○ Male	○ Female	
2. What is your **age**?	_____ years		

3. How long have you worked as an **Air Traffic Controller (include both FAA and military experience)**?	_____ years _____ months
4. How long have you worked as a CPC for the FAA?	_____ years _____ months
5. How long have you **actively controlled traffic** in the en route environment?	_____ years _____ months
6. How long have you **actively controlled traffic** in the terminal environment?	_____ years _____ months
7. How many of the **past 12 months** have you actively controlled traffic?	_____ months

8. Rate your current **skill as a CPC**.	Not Skilled	①②③④⑤⑥⑦⑧⑨⑩	Extremely Skilled
9. Rate your **level of motivation** to participate in this study.	Not Motivated	①②③④⑤⑥⑦⑧⑨⑩	Extremely Motivated

Appendix D

Post-Scenario Questionnaire

POST-SCENARIO QUESTIONNAIRE

Air Traffic Control Tasks

For each of the following major tasks, please rate how well the communication system you just used in the preceding scenario helped you control air traffic. The rating of -5 represents that you thought the system limited or hindered your performance tremendously. The rating of 5 is the opposite: The system helped you perform in a very positive manner. The rating of 0 means no effect.

We have listed subtasks for your reference. Please consult them. Please circle the number that corresponds to your rating for each task.

A. Situation Monitoring: Checking and evaluating separation, Analyzing initial requests for clearances, Processing departure/en route time information, Housekeeping.

B. Resolving Aircraft Conflicts: Performing aircraft conflict resolution, Performing airspace conflict processing, Suppressing/Restoring alerts**.**

C. Managing Air Traffic Sequences: Responding to traffic management constraints/flow conflict, Processing deviations, Establishing arrival sequences, Managing departure flows, Monitoring noncontrolled objects.

D. Routing or planning flights: Planning clearances; Responding to contingencies/emergencies; Responding to special operations; Reviewing flight plans; Processing flight plan amendments; Receiving transfer of control/radar identification; Initiating transfer of control/radar identification; Issuing pointouts; Responding to pointouts; Issuing clearances; Establishing, maintaining, and terminating radio communications; Establishing radar identification.

E. Assessing weather impact: Responding to significant weather information, Processing weather reports.

F. Managing sector/position resources: Assuming position responsibility, Executing backup procedures for communication failures/transient operation, Managing personal workload.

Participant: **Date:** ___________________

	Hindered greatly … Helped greatly
A. Situation monitoring	-5 -4 -3 -2 -1 0 1 2 3 4 5
B. Resolving aircraft conflicts	-5 -4 -3 -2 -1 0 1 2 3 4 5
C. Managing air traffic sequences	-5 -4 -3 -2 -1 0 1 2 3 4 5
D. Routing or planning flights	-5 -4 -3 -2 -1 0 1 2 3 4 5
E. Assessing weather impact	-5 -4 -3 -2 -1 0 1 2 3 4 5
F. Managing sector/position resources	-5 -4 -3 -2 -1 0 1 2 3 4 5

If you have any additional comments about the positive or negative aspects of data communication, please give us your feedback/opinions.

Participant: **Date:** ___________________

Air Traffic Control Communications

For each of the following types of communications, please rate how well you were able to communicate your intentions to the aircraft in the preceding scenario. The rating of *-5* represents that you thought the system limited or hindered your performance tremendously. The rating of *5* is the opposite: The system helped you perform in a very positive manner. The rating of 0 means no effect. Please select N/A when you did not use the feature or do not remember using it.

Please circle the number that corresponds to your rating for each type of communications. On the next page, we have described each communication type for your reference. Please consult them.

Hindered greatly ... Helped greatly

1. Instructions, Advisories, and Report Requests	-5 -4 -3 -2 -1 0 1 2 3 4 5 N/A
2. Route Modifications	
a. Current	-5 -4 -3 -2 -1 0 1 2 3 4 5 N/A
b. Future	-5 -4 -3 -2 -1 0 1 2 3 4 5 N/A
c. Hold	-5 -4 -3 -2 -1 0 1 2 3 4 5 N/A
3. Vertical Clearances	
a. Current	-5 -4 -3 -2 -1 0 1 2 3 4 5 N/A
b. Future	-5 -4 -3 -2 -1 0 1 2 3 4 5 N/A
4. Speed Changes	-5 -4 -3 -2 -1 0 1 2 3 4 5 N/A
5. Heading Changes	-5 -4 -3 -2 -1 0 1 2 3 4 5 N/A
6. Crossing Constraints	
a. Altitude	-5 -4 -3 -2 -1 0 1 2 3 4 5 N/A
b. Speed	-5 -4 -3 -2 -1 0 1 2 3 4 5 N/A
c. Time	-5 -4 -3 -2 -1 0 1 2 3 4 5 N/A
d. Combination	-5 -4 -3 -2 -1 0 1 2 3 4 5 N/A
7. Lateral Offsets	-5 -4 -3 -2 -1 0 1 2 3 4 5 N/A
8. Downlink Request	
a. Altitude	-5 -4 -3 -2 -1 0 1 2 3 4 5 N/A
b. Speed	-5 -4 -3 -2 -1 0 1 2 3 4 5 N/A
c. Route	-5 -4 -3 -2 -1 0 1 2 3 4 5 N/A
9. Voice Frequency Assignments	-5 -4 -3 -2 -1 0 1 2 3 4 5 N/A

Participant: **Date:** __________________

Instructions, Advisories, and Report Requests	Items that do not directly affect the aircraft's trajectory
Route Modifications	
d. Current	A modification to the route that the pilot will execute at his or her earliest convenience as soon as possible
e. Future	A modification to the route that will not take effect to a later point in time, space, or after completing another ??
f. Hold	A Holding instruction
Vertical Clearances	
a. Current	An altitude clearance that the pilot will execute as soon as possible
b. Future	An altitude clearance that the pilot will take effect to a later point in time
Speed Changes	Speed clearances
Heading Changes	Heading clearances
Crossing Constraints	
a. Altitude	An instruction to cross a position at a specified altitude
b. Speed	An instruction to cross a position at a specified speed
c. Time	An instruction to cross a position at a specified time
d. Combination	An instruction to cross a position meeting a combination of constraints
Lateral Offsets	An instruction to fly an offset at a defined number of miles left or right of route
Downlink Request	
a. Altitude	A request from a pilot to change current altitude to a preferred level
b. Speed	A request from a pilot to change current speed to a preferred speed
c. Route	A request from a pilot to change current route to a preferred route
Voice Frequency Assignments	An instruction to contact a sector or facility at a frequency or to monitor a frequency

Appendix E

Exit Questionnaire

Participant: **Date:** ___________________

1. Human Machine Interface Mode

Please rate your overall preference of use for each of the human machine interface modes. The rating of -5 represents that you thought the system limited or hindered your performance tremendously. The rating of 5 is the opposite: The system helped you perform in a very positive manner. The rating of 0 means that it had no effect. Please circle the number that corresponds to your rating for each human machine interface mode.

a. Please indicate your preference for using the ***keyboard*** as the sole input mode for data communication. Please circle the number as your rating.

Absolutely not **Absolutely**

-5	-4	-3	-2	-1	0	1	2	3	4	5

Justification for your ratings:

b. Please indicate your preference for using the ***template*** as the sole input mode for data communication. Please circle the number as your rating.

Absolutely not **Absolutely**

-5	-4	-3	-2	-1	0	1	2	3	4	5

Justification for your ratings:

c. Please indicate your preference for using the ***graphical interface*** as the sole input mode for data communication. Please circle the number as your rating.

Absolutely not **Absolutely**

-5	-4	-3	-2	-1	0	1	2	3	4	5

Justification for your ratings:

d. Please indicate your preference for using the ***combined*** input mode for data communication. Please circle the number as your rating.

Absolutely not **Absolutely**

-5	-4	-3	-2	-1	0	1	2	3	4	5

Justification for your ratings:

Participant: **Date: ________________**

2. Experimental Factors

You experienced different types and levels of experimental factors. For each experimental factor, please rate how well different types and levels affected your data communication. Please rate them according to the degree of benefiting for your controlling air traffic. Some may have affected your performance negatively, which you would rate with negative numbers. The rating of 0 would represent no effect at all. The positive ratings means you performed better by using them. After circling the numbers of your rating, please describe your justification of the rating.

1. You used two service priorities. Please rate each of them in terms of efficiency in controlling air traffic.
First-Come, First-Served Priority **Very Limiting** **Very Useful** -5 -4 -3 -2 -1 0 1 2 3 4 5
Best-Equipped, Best-Served Priority **Very Limiting** **Very Useful** -5 -4 -3 -2 -1 0 1 2 3 4 5
Justification for your ratings:
2. When 50% of the aircraft in the sector had the capability of data communication, please rate the benefit of having multiple aircraft with the FMS integrated for your air traffic control task
When 50% of the aircraft had the integrated FMS **Very Limiting** **Very Useful** -5 -4 -3 -2 -1 0 1 2 3 4 5
When 100% of the aircraft had the integrated FMS **Very Limiting** **Very Useful** -5 -4 -3 -2 -1 0 1 2 3 4 5
Justification for your ratings:

Participant: **Date: ___________________**

3. When 100% of the aircraft in the sector had the capability of data communication, please rate the benefit of having multiple aircraft with the FMS integrated for your air traffic control task
When 50% of the aircraft had the integrated FMS **Very Limiting** **Very Useful** -5 -4 -3 -2 -1 0 1 2 3 4 5
When 100% of the aircraft had the integrated FMS **Very Limiting** **Very Useful** -5 -4 -3 -2 -1 0 1 2 3 4 5
Justification for your ratings:
4. When the data communication system failed in one or more aircraft, please rate the degree of the detrimental effect in controlling air traffic.
When a single aircraft's data communication failed **Not Detrimental At All** **Very Detrimental** 1 2 3 4 5 6 7 8 9 10
When a few aircraft's data communication failed **Not Detrimental At All** **Very Detrimental** 1 2 3 4 5 6 7 8 9 10
When all of the aircraft's data communication failed **Not Detrimental At All** **Very Detrimental** 1 2 3 4 5 6 7 8 9 10
Justification for your ratings:
5. Please rate the detrimental effect of data communication delays of 8/30 seconds and 5/10 seconds in air traffic control.
When the delay was 8/30 seconds **Not Detrimental At All** **Very Detrimental** 1 2 3 4 5 6 7 8 9 10
When the delay was 5/10 seconds **Not Detrimental At All** **Very Detrimental** 1 2 3 4 5 6 7 8 9 10
Justification for your ratings:

Participant: **Date:** ___________________

3. Evaluation of Data Communication Features

We listed the general data communication features below. These are concepts, and we need your input. You already experienced these separately or together during the simulation experiment. We will ask you about each one separately if it is a desirable feature for safer and more efficient air traffic control. All of them are feasible under the data communication environment.

Please rate one by one. The rating of -5 indicates that the particular feature limited and hindered your performance tremendously. The rating of 5 is the opposite, that is, it helped you perform in a very positive way. You can use a rating of 0 to indicate that the feature did not affect your performance.

	Feature	Hindered greatly										Helped greatly
1.	Blinking the affected field if aircraft does not follow the instruction issued.	-5	-4	-3	-2	-1	0	1	2	3	4	5
2.	Future clearance indicator showing *, ○, and ●.	-5	-4	-3	-2	-1	0	1	2	3	4	5
3.	Data Communication portal on line 0, Voice portal on line 1, and radio portal on line 3.	-5	-4	-3	-2	-1	0	1	2	3	4	5
4.	External request indicator on the right side of the Mode C indicator on the FDB second line.	-5	-4	-3	-2	-1	0	1	2	3	4	5
5.	Indicating proposed-clearances status.	-5	-4	-3	-2	-1	0	1	2	3	4	5
6.	Display of sent messages.	-5	-4	-3	-2	-1	0	1	2	3	4	5
7.	Log of sent and received messages.	-5	-4	-3	-2	-1	0	1	2	3	4	5
8.	Display of received messages.	-5	-4	-3	-2	-1	0	1	2	3	4	5
9.	Displaying and modifying trajectory graphically.	-5	-4	-3	-2	-1	0	1	2	3	4	5
10.	Displaying and modifying trajectory through template.	-5	-4	-3	-2	-1	0	1	2	3	4	5
11.	Displaying and modifying trajectory using keyboard/response/message composition area.	-5	-4	-3	-2	-1	0	1	2	3	4	5
12.	Sharing a trajectory between positions.	-5	-4	-3	-2	-1	0	1	2	3	4	5
13.	Updating times over fixes when graphically modifying a trajectory.	-5	-4	-3	-2	-1	0	1	2	3	4	5
14.	Updating conflict probe status when graphically modifying a trajectory.	-5	-4	-3	-2	-1	0	1	2	3	4	5
15.	Symbology for clearances and restrictions.	-5	-4	-3	-2	-1	0	1	2	3	4	5
16.	Abbreviations for clearances and restrictions.	-5	-4	-3	-2	-1	0	1	2	3	4	5
17.	Function keys for clearances and restrictions.	-5	-4	-3	-2	-1	0	1	2	3	4	5
18.	Symbology of eligibility for data communication.	-5	-4	-3	-2	-1	0	1	2	3	4	5
19.	Message display format.	-5	-4	-3	-2	-1	0	1	2	3	4	5
20.	Status view of ToC/Outage view.	-5	-4	-3	-2	-1	0	1	2	3	4	5
21.	Status Mode of ToC/Outage view.	-5	-4	-3	-2	-1	0	1	2	3	4	5
22.	Sending a trajectory update to multiple aircraft.	-5	-4	-3	-2	-1	0	1	2	3	4	5
23.	Change of D-side roles and responsibilities.	-5	-4	-3	-2	-1	0	1	2	3	4	5
24.	Linking aircraft representations	-5	-4	-3	-2	-1	0	1	2	3	4	5
25.	Emphasizing aircraft that share a feature.	-5	-4	-3	-2	-1	0	1	2	3	4	5
26.	Integrating data communication on the aircraft list.	-5	-4	-3	-2	-1	0	1	2	3	4	5

Participant: **Date:** ___________________

4. Simulation Realism and Research Apparatus Ratings

1. How **realistic** was the overall simulation experience compared to actual operations?	Unrealistic	1	2	3	4	5	6	7	8	9	10	Realistic
2. How **representative** were the scenarios of a typical workday?	Not Representative	1	2	3	4	5	6	7	8	9	10	Representative
3. How **realistic was the generic airspace** compared to actual NAS airspace?	Unrealistic	1	2	3	4	5	6	7	8	9	10	Realistic
4. To what extent did the **ATWIT online workload rating interfere** with your ATC performance?	Not At All	1	2	3	4	5	6	7	8	9	10	A Great Deal
5. To what extent did the **oculometer interfere** with your ATC performance?	Not At All	1	2	3	4	5	6	7	8	9	10	A Great Deal
6. How well did the **simulation pilots** respond to your clearances in terms of traffic movement and callbacks?	Extremely Poorly	1	2	3	4	5	6	7	8	9	10	Extremely Well
7. How effective was the **training** provided on each system?	Not Effective	1	2	3	4	5	6	7	8	9	10	Extremely Effective

Please include any additional comments about the simulation that you would like us to know about.

Participant: **Date:** ___________________

The following sections are a topic checklist for the structured interview debriefing, to be used by the researchers.

1. Failure Mode

In some scenarios a single, multiple, or all aircraft lost Data Communication capability. How did the individual-aircraft data communication failure affect your controlling air traffic? How were the multiple aircraft failure and the total failure?

In the above, you answered the effect of data communication failure on air traffic control. Do you think the effect would be different depending on how many aircraft had data communication capability in the sector? Please describe the effect of the different levels of each factor separately and interactions between them.

2. Data Communication Equipage Levels

In some scenarios, a few aircraft (10%, 50%, or 100% of the aircraft in the sector) had data communication capability. Did the various equipage levels in the sector affect your air traffic control differently? Was it dependent on the input mode you used, flight management system integration levels, and service priority? If it was, please describe the difference.

3. Service Preference

In some scenarios, you gave service preference to aircraft that had data communication. Did it help you control traffic more efficiently? Please describe the benefit of this policy over the first-come-first service policy if there is any. If it did not help you, please describe it why it did not help, or how it hindered your air traffic control performance.

4. FMS Integration Levels

Depending on a scenario, we changed the number of aircraft in the sector that had the integrated FMS: 50% or 100%.

Did these different proportions matter when you used data communication? That is, when a certain proportion of the total aircraft in the sector (50%, or 100%) had the integrated FMS, was it easier for you to control air traffic than when you had a different number of FMS-integrated aircraft in the sector (50%, or 100%)?

Also, did it (the number of aircraft that had integrated FMS capability) affect your controlling air traffic in a different way depending on the number of aircraft in the sector that had data communication? If it did, please describe the effect of this interaction between FMS and Data Communication capabilities on your controlling air traffic.

5. R- and D-side Roles and Responsibility in Data Communication Environment

Data communication brings new capabilities in coordination and corporations between R- and D-sides. It also brings new capability in information exchange and coordination between controllers and the system. We wish to hear your opinions on this aspect of data communication. As you already have noticed, an example between two controllers is to have the same workstation capability. This must have changed the roles of the R- and D-sides. Please let us know your opinions on the changes that data communication brings to your controlling air traffic.

6. Human Machine Interface effectiveness

What was the most effective HMI design for data communication input mode? Would you describe why it was the best mode? If it depended on the number of aircraft in the sector that had data communication equipage, please explain it.

Appendix F

Over-The-Shoulder Rating Form

Instructions for questions 1-31

Please evaluate the effectiveness of the controllers. Please write down observations and make preliminary ratings during the course of the scenario. However, please wait until the scenario is finished before making your final ratings. The observations you make do not need to be restricted to the performance areas covered in this form and may include other areas that you think are important. Also, please write down any comments that may improve this evaluation form. Your identity will remain anonymous, so do not write your name on the form.

Rating	Label Description
1	Controller demonstrated extremely poor judgment in making control decisions and very frequently made errors.
2	Controller demonstrated poor judgment in making some control decisions and occasionally made errors.
3	Controller made questionable decisions using poor control techniques which led to restricting the normal traffic flow.
4	Controller demonstrated the ability to keep aircraft separated but used spacing and separation criteria which were excessive.
5	Controller demonstrated adequate judgment in making control decisions.
6	Controller demonstrated good judgment in making control decisions using efficient control techniques.
7	Controller frequently demonstrated excellent judgment in making control decisions using extremely good control techniques.
8	Controller always demonstrated excellent judgment in making even the most difficult control decisions while using outstanding control techniques.

Maintaining Safe and Efficient Traffic Flow

1. Maintaining Separation and Resolving Potential Conflicts - using control instructions that maintain safe aircraft separation - detecting and resolving impending conflicts early	1 2 3 4 5 6 7 8
2. Sequencing Arrival and Departure Aircraft Efficiently - using efficient and orderly spacing techniques for arrival and departure aircraft - maintaining safe arrival and departure intervals that minimize delays	1 2 3 4 5 6 7 8
3. Using Control Instructions Effectively - providing accurate navigational assistance to pilots - avoiding clearances that result in the need for additional instructions to handle aircraft completely - avoiding excessive vectoring or over-controlling	1 2 3 4 5 6 7 8
4. Overall Safe and Efficient Traffic Flow	1 2 3 4 5 6 7 8

Maintaining Attention and Situation Awareness

5. Maintaining Awareness of Aircraft Positions - avoiding fixation on one area of the radar scope when other areas need attention - using scanning patterns that monitor all aircraft on the radar scope	1 2 3 4 5 6 7 8
6. Ensuring Positive Control	1 2 3 4 5 6 7 8
7. Detecting Pilot Deviations from Control Instructions - ensuring that pilots follow assigned clearances correctly - correcting pilot deviations in a timely manner - avoiding excessive vectoring or over-controlling	1 2 3 4 5 6 7 8
8. Correcting Own Errors in a Timely Manner	1 2 3 4 5 6 7 8
9. Overall Attention and Situation Awareness	1 2 3 4 5 6 7 8

Prioritizing

10. Taking Actions in an Appropriate Order of Importance - resolving situations that need immediate attention before handling low priority tasks - issuing control instructions in a prioritized, structured, and timely manner	1 2 3 4 5 6 7 8
11. Preplanning Control Actions - scanning adjacent sectors to plan for inbound traffic	1 2 3 4 5 6 7 8
12. Handling Control Tasks for Several Aircraft - shifting control tasks between aircraft - avoiding delays in communications while thinking or planning control actions	1 2 3 4 5 6 7 8
13. Overall Prioritizing	1 2 3 4 5 6 7 8

Providing Control Information	
14. Providing Essential ATC Information - providing mandatory services and advisories to pilots in a timely manner - exchanging essential information	1 2 3 4 5 6 7 8
15. Providing Additional ATC Information - providing additional services when workload is not a factor - exchanging additional information	1 2 3 4 5 6 7 8
16. Overall Providing Control Information	1 2 3 4 5 6 7 8
Technical Knowledge	
17. Showing Knowledge of LOAs and SOPs - controlling traffic as depicted in current LOAs and SOPs - performing handoff procedures correctly	1 2 3 4 5 6 7 8
18. Showing Knowledge of Aircraft Capabilities and Limitations - avoiding clearances that are beyond aircraft performance parameters - recognizing the need for speed restrictions and wake turbulence separation	1 2 3 4 5 6 7 8
19. Overall Technical Knowledge	1 2 3 4 5 6 7 8
Voice Communications	
20. Using Proper Phraseology - using words and phrases specified in JO 7110.65S - using proper phraseology that is appropriate for the situation - avoiding the use of excessive verbiage	1 2 3 4 5 6 7 8
21. Communicating Clearly and Efficiently - speaking at the proper volume and rate for pilots to understand - speaking fluently while scanning or performing other tasks - clearance delivery is complete, correct and timely - providing complete information in each clearance	1 2 3 4 5 6 7 8
22. Listening for pilot readbacks and requests - correcting pilot readback errors - processing requests correctly in a timely manner	1 2 3 4 5 6 7 8
23. Overall Voice Communication	1 2 3 4 5 6 7 8
Data Communications (if applicable)	
24. Using Data Comm in appropriate situations - use in non-time-critical situations - equipped a/c only	1 2 3 4 5 6 7 8
25. Communicating Efficiently - choose efficient message combinations - clearance delivery is complete, correct and timely - use complex clearances appropriately - take full advantage of Data Comm message set	1 2 3 4 5 6 7 8
26. Monitoring Data Comm feedback and pilot replies and requests - Msg In, Msg Out, Msg Fail windows; DB field highlighting - processing requests correctly in a timely manner	1 2 3 4 5 6 7 8
27. Overall Data Communication	1 2 3 4 5 6 7 8
Teamwork	
28. Task Allocation between R-and D-sides - precoordinated plan (preferred); on-the-fly; none (least preferred) - redundant vs. complementary action	1 2 3 4 5 6 7 8
29. Team Communication - information sharing - appropriate use: verbal, non-verbal (pointing), graphical - communicate working conventions (DB placement)	1 2 3 4 5 6 7 8
30. Team SA - anticipation of information need - reminder of pending actions	1 2 3 4 5 6 7 8
31. Overall Data Communication	1 2 3 4 5 6 7 8

Appendix G

Instructions for Participants

INSTRUCTIONS FOR PARTICIPANTS

General Training Scenario Instructions

During the training scenarios, you will have the opportunity to become familiar with your position and the features and functions of the system with which you will be working. You will also have the opportunity to become familiar with the simulated Voice Switching and Control System, the oculometer, and the Workload Assessment Keypads. The training scenarios will help you prepare for the test scenarios that will follow, and we encourage you to ask questions as needed throughout training to make sure that you understand the use of all available capabilities. (We will then provide the relevant instructions for the training condition that will follow.)

WAK Instructions

(The full set of instructions will be read at the beginning of each test day. An abbreviated set of instructions will be read prior to each experimental run. The abbreviated instructions will omit the first paragraph below.)

One purpose of this research is to obtain an accurate evaluation of controller workload. By workload, we mean all the physical and mental effort that you must exert to do your job. This includes maintaining the "picture," planning, coordinating, decision making, communicating, and whatever else is required to maintain a safe and expeditious traffic flow. Workload is your perception of how hard you must work to perform all of the tasks necessary to meet these demands, not necessarily a measure of how much traffic you are working. Workload levels fluctuate. All controllers, no matter how proficient, will experience all levels of workload at one time or another. It does not detract from a controller's professionalism to indicate that he or she is working very hard at certain times or at he is hardly working at other times.

Every 2 minutes the WAK device located at your position will emit a brief tone and the 10 buttons will illuminate. The buttons will remain lit for 20 seconds. Please tell us what your workload is at that moment by pushing one of the buttons numbered from 1 to 10.

At the low end of the scale (1 or 2), your workload is low - you can accomplish everything easily. As the numbers increase, your workload is getting higher. The numbers 3, 4, and 5 represent increasing levels of moderate workload, where the chance of making a mistake (e.g., leaving a task unfinished) is still low but steadily increasing. The numbers 6, 7, and 8 reflect relatively high workload, where there is some chance of making a mistake. At the high end of the scale are the numbers 9 and 10, which represent a very high workload, where it is likely that you will have to leave some tasks unfinished. Feel free to use the entire rating scale and tell us honestly how hard you are working at the instant that you are prompted. Do not sacrifice the safe and expeditious flow of traffic to respond to the WAK device. If you do not respond within the 20 seconds, we will assume that you were too busy with traffic to be distracted, and we will record your workload rating as 10.

Does anyone have any questions?

Appendix H

Over-The-Shoulder Ratings Factor Analysis

OVER-THE-SHOULDER RATINGS FACTOR ANALYSIS

Subject-Matter Experts (SMEs) rated ATC performance in all test scenarios of the En Route Data Comm simulation, using a battery of 31 rating scales, the OTS (see Appendix F).

Multivariate analyses of the OTS indicated that many of the scales were correlated. A standard analysis of such scales is Principal Components Analysis, a statistical procedure to identify the factors that underlie the patterns of correlation among rating scales. For this purpose, only the ratings from the baseline control condition were used. This scenario was always the fourth test run, always had 50% Data Comm-equipped aircraft, presented no simulated failures, and held all other experimental factors constant.

Table H-1 shows the correlation matrix for the scales. The Varimax procedure was applied to rotate the principal axes such that the maximum amount of variability is accounted for while maintaining orthogonality (statistical independence) of the principal components. Five component eigenvectors had Eigen values greater than one, and were retained.

We considered the pattern of loadings on the original OTS items: Table H-1 Correlation Matrix of 31 OTS Rating Items.

Table H1. Correlation Matrix of 31 OTS Rating Items

Item	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
1	–	0.71	0.89	1	0.69	0.96	0.87	0.89	0.89	0.90	0.69	0.90	0.90	0.66	0.44	0.70	0.78	0.61	0.69	0.56	0.73	0.67	0.63	0.83	0.53	0.27	0.59	0.77	0.61	0.79	0.77
2	0.71	–	0.80	0.71	0.30	0.71	0.90	0.59	0.59	0.65	0.89	0.65	0.65	0.47	0.76	0.69	0.68	0.90	0.87	0.22	0.54	0.26	0.25	0.56	0.34	0.54	0.43	0.63	0.63	0.64	0.63
3	0.89	0.80	–	0.89	0.74	0.79	0.82	0.73	0.73	0.81	0.74	0.81	0.81	0.58	0.50	0.66	0.85	0.67	0.73	0.47	0.67	0.56	0.52	0.69	0.43	0.20	0.53	0.79	0.62	0.79	0.79
4	1	0.71	0.89	–	0.69	0.96	0.87	0.89	0.89	0.90	0.69	0.90	0.90	0.66	0.44	0.70	0.78	0.61	0.69	0.56	0.73	0.67	0.63	0.83	0.53	0.27	0.59	0.77	0.61	0.79	0.77
5	0.69	0.30	0.74	0.69	–	0.66	0.40	0.74	0.74	0.66	0.50	0.66	0.66	0.45	0.15	0.39	0.79	0.31	0.47	0.55	0.60	0.66	0.57	0.62	0.55	0	0.43	0.68	0.54	0.66	0.68
6	0.96	0.71	0.79	0.96	0.66	–	0.83	0.97	0.97	0.87	0.78	0.87	0.87	0.63	0.52	0.71	0.80	0.70	0.77	0.51	0.72	0.61	0.57	0.87	0.64	0.44	0.58	0.77	0.71	0.78	0.77
7	0.87	0.90	0.82	0.87	0.40	0.83	–	0.67	0.67	0.79	0.81	0.79	0.79	0.57	0.56	0.68	0.62	0.73	0.79	0.44	0.67	0.53	0.49	0.64	0.39	0.42	0.53	0.62	0.49	0.62	0.62
8	0.89	0.59	0.73	0.89	0.74	0.97	0.67	–	1	0.81	0.74	0.81	0.81	0.58	0.50	0.66	0.85	0.67	0.73	0.47	0.67	0.56	0.52	0.87	0.70	0.43	0.53	0.79	0.78	0.79	0.79
9	0.89	0.59	0.73	0.89	0.74	0.97	0.67	1	–	0.81	0.74	0.81	0.81	0.58	0.50	0.66	0.85	0.67	0.73	0.47	0.67	0.56	0.52	0.87	0.70	0.43	0.53	0.79	0.78	0.79	0.79
10	0.90	0.65	0.81	0.90	0.66	0.87	0.79	0.81	0.81	–	0.66	0.79	0.79	0.74	0.39	0.75	0.73	0.57	0.67	0.66	0.79	0.57	0.56	0.82	0.64	0.14	0.66	0.77	0.61	0.80	0.77
11	0.69	0.89	0.74	0.69	0.50	0.78	0.81	0.74	0.74	0.66	–	0.66	0.66	0.45	0.75	0.66	0.79	0.93	0.95	0.27	0.60	0.33	0.28	0.62	0.55	0.64	0.43	0.68	0.76	0.66	0.68
12	0.90	0.65	0.81	0.90	0.66	0.87	0.79	0.81	0.81	0.79	0.66	–	1	0.74	0.39	0.75	0.73	0.57	0.67	0.48	0.63	0.57	0.56	0.82	0.40	0.35	0.66	0.77	0.61	0.63	0.77
13	0.90	0.65	0.81	0.90	0.66	0.87	0.79	0.81	0.81	0.79	0.66	1	–	0.74	0.39	0.75	0.73	0.57	0.67	0.48	0.63	0.57	0.56	0.82	0.40	0.35	0.66	0.77	0.61	0.63	0.77
14	0.66	0.47	0.58	0.66	0.45	0.63	0.57	0.58	0.58	0.74	0.45	0.74	0.74	–	0.56	0.94	0.59	0.47	0.55	0.57	0.65	0.45	0.49	0.78	0.53	0.25	0.80	0.76	0.61	0.65	0.76
15	0.44	0.76	0.50	0.44	0.15	0.52	0.56	0.50	0.50	0.39	0.75	0.39	0.39	0.56	–	0.78	0.63	0.87	0.80	0.08	0.39	0.10	0.11	0.51	0.45	0.69	0.39	0.58	0.72	0.58	0.58
16	0.70	0.69	0.66	0.70	0.39	0.71	0.68	0.66	0.66	0.75	0.66	0.75	0.75	0.94	0.78	–	0.72	0.73	0.75	0.41	0.61	0.32	0.35	0.79	0.53	0.45	0.72	0.80	0.75	0.71	0.80
17	0.78	0.68	0.85	0.78	0.79	0.80	0.62	0.85	0.85	0.73	0.79	0.73	0.73	0.59	0.63	0.72	–	0.79	0.85	0.40	0.63	0.47	0.42	0.80	0.65	0.43	0.57	0.88	0.87	0.86	0.88
18	0.61	0.90	0.67	0.61	0.31	0.70	0.73	0.67	0.67	0.57	0.93	0.57	0.57	0.47	0.87	0.73	0.79	–	0.96	0.14	0.50	0.17	0.15	0.63	0.51	0.73	0.45	0.69	0.82	0.67	0.69
19	0.69	0.87	0.73	0.69	0.47	0.77	0.79	0.73	0.73	0.67	0.95	0.67	0.67	0.55	0.80	0.75	0.85	0.96	–	0.30	0.62	0.36	0.30	0.69	0.60	0.69	0.55	0.75	0.80	0.71	0.75
20	0.56	0.22	0.47	0.56	0.55	0.51	0.44	0.47	0.47	0.66	0.27	0.48	0.48	0.57	0.08	0.41	0.40	0.14	0.30	–	0.93	0.84	0.93	0.68	0.74	-0.06	0.79	0.65	0.39	0.67	0.65
21	0.73	0.54	0.67	0.73	0.60	0.72	0.67	0.67	0.67	0.79	0.60	0.63	0.63	0.65	0.39	0.61	0.63	0.50	0.62	0.93	–	0.79	0.87	0.82	0.83	0.21	0.84	0.82	0.65	0.83	0.82
22	0.67	0.26	0.56	0.67	0.66	0.61	0.53	0.56	0.56	0.57	0.33	0.57	0.57	0.45	0.10	0.32	0.47	0.17	0.36	0.84	0.79	–	0.93	0.65	0.64	0.14	0.66	0.60	0.33	0.63	0.60
23	0.63	0.25	0.52	0.63	0.57	0.57	0.49	0.52	0.52	0.56	0.28	0.56	0.56	0.49	0.11	0.35	0.42	0.15	0.30	0.93	0.87	0.93	–	0.69	0.65	0.05	0.74	0.64	0.38	0.65	0.64
24	0.83	0.56	0.69	0.83	0.62	0.87	0.64	0.87	0.87	0.82	0.62	0.82	0.82	0.78	0.51	0.79	0.80	0.63	0.69	0.68	0.82	0.65	0.69	–	0.81	0.46	0.86	0.94	0.85	0.89	0.94
25	0.53	0.34	0.43	0.53	0.55	0.64	0.39	0.70	0.70	0.64	0.55	0.40	0.40	0.53	0.45	0.53	0.65	0.51	0.60	0.74	0.83	0.64	0.65	0.81	–	0.42	0.74	0.78	0.77	0.84	0.78
26	0.27	0.54	0.20	0.27	0	0.44	0.42	0.43	0.43	0.14	0.64	0.35	0.35	0.25	0.69	0.45	0.43	0.73	0.69	-0.06	0.21	0.14	0.05	0.46	0.42	–	0.37	0.43	0.61	0.34	0.43
27	0.59	0.43	0.53	0.59	0.43	0.58	0.53	0.53	0.53	0.66	0.43	0.66	0.66	0.80	0.39	0.72	0.57	0.45	0.55	0.79	0.84	0.66	0.74	0.86	0.74	0.37	–	0.87	0.69	0.76	0.87
28	0.77	0.63	0.79	0.77	0.68	0.77	0.62	0.79	0.79	0.77	0.68	0.77	0.77	0.76	0.58	0.80	0.88	0.69	0.75	0.65	0.82	0.60	0.64	0.94	0.78	0.43	0.87	–	0.91	0.94	1
29	0.61	0.63	0.62	0.61	0.54	0.71	0.49	0.78	0.78	0.61	0.76	0.61	0.61	0.61	0.72	0.75	0.87	0.82	0.80	0.39	0.65	0.33	0.38	0.85	0.77	0.61	0.69	0.91	–	0.85	0.91
30	0.79	0.64	0.79	0.79	0.66	0.78	0.62	0.79	0.79	0.80	0.66	0.63	0.63	0.65	0.58	0.71	0.86	0.67	0.71	0.67	0.83	0.63	0.65	0.89	0.84	0.34	0.76	0.94	0.85	–	0.94
31	0.77	0.63	0.79	0.77	0.68	0.77	0.62	0.79	0.79	0.77	0.68	0.77	0.77	0.76	0.58	0.80	0.88	0.69	0.75	0.65	0.82	0.60	0.64	0.94	0.78	0.43	0.87	1	0.91	0.94	–

Table H2. Factor Loadings and Tentative Names

OTS Item No	Item Description	Loading
	Factor 1: Communicating Clearly and Efficiently	
20	Using Proper Phraseology	.926
23	Overall Communicating	.899
22	Listening for Pilot Readbacks and Requests	.833
21	Communicating Clearly and Efficiently	.822
25	Communicating Efficiently	.700
27	Overall Data Communication	.689
30	Team SA	.547
24	Using Data Comm in appropriate situations	.514
	Factor 2: Strategic Air Traffic Control	
18	Showing Knowledge of Aircraft Capabilities and Limitations	.881
15	Providing Additional ATC Information	.845
26	Monitoring Data Comm feedback and pilot replies and requests	.830
19	Overall Technical Knowledge	.791
11	Preplanning Control Actions	.776
2	Sequencing Arrival and Departure Aircraft Efficiently	.752
29	Team Communication	.612
	Factor 3: Tactical Air Traffic Control	
1	Maintaining Separation and Resolving Potential Conflicts	.803
4	Overall Safe and Efficient Traffic Flow	.803
7	Detecting Pilot Deviations from Control Instructions	.781
12	Handling Control Tasks for Several Aircraft	.766
13	Overall Prioritizing	.766
3	Using Control Instructions Effectively	.750
6	Ensuring Positive Control	.696
10	Taking Actions in an Appropriate Order of Importance	.665
	Factor 4: Situation Awareness	
5	Maintaining Awareness of Aircraft Positions	.692
17	Showing Knowledge of LOAs and SOPs	.639
8	Correcting Own Errors in a Timely Manner	.625
9	Overall Attention and Situation Awareness	.625
28	Task Allocation between R- and D-side	.481
31	Overall Data Communication [Teamwork?]	.481
	Factor 5: Providing Information	
14	Providing Essential ATC Information	.813
16	Overall Providing Control Information	.728

Appendix I

Proximity Events

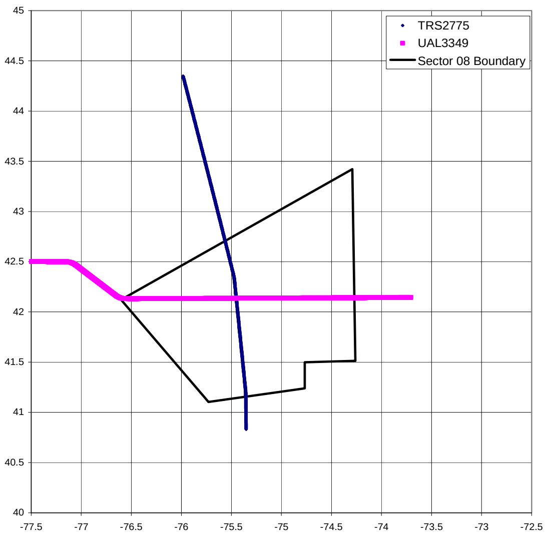
PROXIMITY EVENTS

In each proximity incident, we present a short description, controllers and pilots' activities related to the two aircraft involved, and top-down view and vertical view.

Proximity Incident #1 between TRS 2775 and UAL3349 (T04FTN1c100_050R03)

The following table presents a detailed account of the interactions of the controller team with the system and simulation pilots. At 0:36:52 the conflict alert algorithm detected a potential conflict between TRS2775 and ASA3635. TRS2775 was level at FL370 and ASA3635 was climbing through FL340 to FL380. The R-side controller instructed TRS2775 to descend to an interim altitude of FL300 that would take TRS2775 out of the potential conflict situation. The R-side controller correctly used voice to implement the altitude change for the TRS2775 aircraft, because this was a tactical situation. Although the R-side controller attempted to enter the interim altitude of FL300, the entry resulted in an error. The D-side controller heard the R-side's voice clearance and made the entry for him. The TRS2775 started to descend. At 0:37:30 the R-side started to clear the aircraft by voice, but discussed sending the aircraft direct to LANCE and used Data Comm instead. The R-side controller monitored TRS2775 and thought that it would clear UAL3349. Conflict alert did not go off and UAL3349 caught the back-end of TRS2775 before TRS2775 leveled off. The two aircraft loose separation at 0:40:07 for 38 seconds. Closest Point of Approach is 3.7 nautical miles laterally and 689 feet vertically.

Start	ACID	Task	Modality	Content	Position
00:31:28.036	TRS2775	HandoffAccept	nas	TRS2775	D-side
00:32:49.603	UAL3349	HandoffAccept	nas	155	D-side
00:32:59.000	TRS2775	MonitorFrequency	datalink	CC 120080	Pilot
00:33:50.000	UAL3349		Voice	United 33 49 cleared to dev… errr… will direct New Jersey work?	R-side
00:33:55.000	UAL3349		Voice	United 33 49 cleared direct New Jersey. Let me know if you need to deviate any further.	R-side
00:33:55.334	UAL3349	MacroTearoffButton25	nas	QU NJY: UAL3349	D-side
00:34:04.000	UAL3349	DirectToFix	nas	DIR NJY	Pilot
00:35:26.653	TRS2775	LeaderChangeRequest	nas	4 TRS2775	R-side
00:37:02.000	TRS2775		Voice	Citrus 27 75 Descend and Maintain Flight Level 3 0 0	R-side
00:37:06.889		ERROR	nas	QQ 300 (-29063,171590)	R-side
00:37:07.953	TRS2775	AssignInterimAltitude	nas	QQ 300 704	D-side
00:37:11.000	TRS2775	DescendAndMaintain	nas	A300	Pilot
00:37:15.540	TRS2775	ModifyRoute	datalink	QU LANCE S TRS2775	R-side
00:38:08.000	TRS2775	DirectToFix	datalink	DIR LANCE;	Pilot
00:39:53.000			Voice	Ah that works	R-side
00:40:17.000			Voice	I came close to it. Ah I gues did have a mid… Oh well.	R-side
00:40:20.490	TRS2775	RemoveInterimAltitude	nas	QQ 704	D-side
00:40:23.273	TRS2775	AssignInterimAltitude	nas	QQ 280 704	D-side
00:40:28.844	TRS2775	LeaderChangeRequest	nas	8 704	D-side
00:40:32.780	TRS2775	LeaderChangeRequest	nas	7 TRS2775	R-side
00:40:32.896	TRS2775	QSL	datalink	QS /310 S TRS2775	D-side
00:40:38.477	UAL3349	LeaderChangeRequest	nas	9 155	D-side
00:40:44.000	TRS2775	CrossFixAtAltitude ReduceSpeed	nas	A280 DIR LANCE S310	Pilot
00:41:04.000	TRS2775		Voice	Citrus 27 75 Cross Lance at maintain flight level 280 Maintain 310 knots when able.	R-side
00:43:51.333	UAL3349	HandoffRequest	nas	07 155	R-side
00:44:32.486	TRS2775	UH	nas	UH TRS2775	R-side
00:44:44.971	TRS2775	LeaderChangeRequest	nas	4/0 704	D-side
00:45:15.000	TRS2775	ContactController	datalink	CC 120220	Pilot
00:46:59.833	UAL3349	DROP-FDB	nas	155	R-side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UAL3349
Sector 08 Boundary
45
44.5
44
43.5
43
42.5
42
41.5
41
40.5
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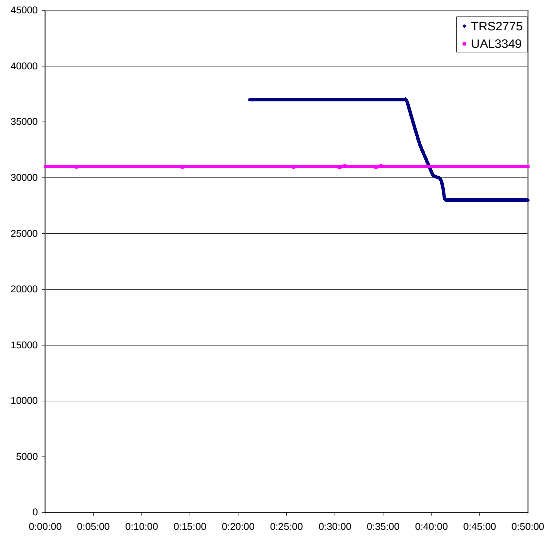
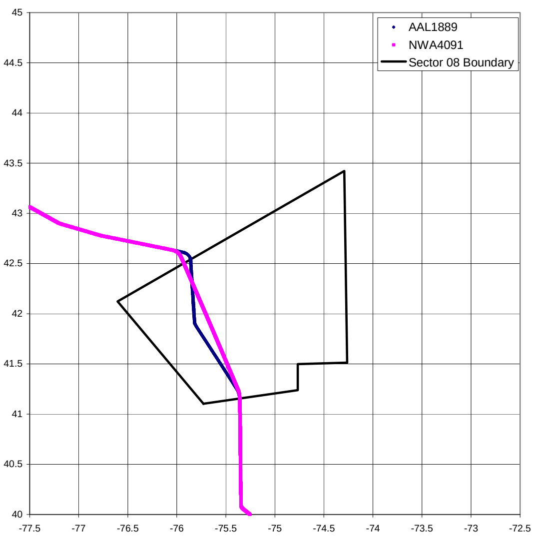
-73
-72.5

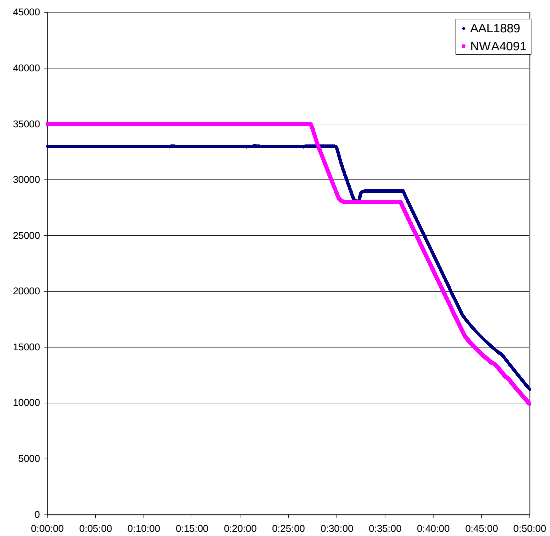

TRS2775
UAL3349
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0:00:00
0:05:00
0:10:00
0:15:00
0:20:00
0:25:00
0:30:00
0:35:00
0:40:00
0:45:00
0:50:00

Proximity Incident #2 between AAL1889 and NWA4091 (T05FCN11100_100R07)

The controller tried to separate the aircraft that both had a crossing restriction of FL290 AT LANCE, but the trailing aircraft ran over the lead aircraft. Conflict alert went off, but separation was not lost until the aircraft reached sector 22. Initially there was no overtake situation, but the controller tried to separate the aircraft further by sending a REDUCE SPEED TO 310 KNOTS OR LESS to the trailing aircraft, AAL1889, and an INCREASE SPEED TO 320 KNOTS OR GREATER to the lead aircraft, NWA4091. Both aircraft were flying at approximately 270 KNOTS indicated airspeed, and their Traffic Management Advisor (TMA) Delay Countdown Time (DCT) showed that they could speed up a little (approximately 50 and 40 seconds for AAL1889 and NWA3964, respectively). The trailing aircraft, AAL1889, was an MD80 and followed the uplinked instruction to speed up to 310 knots indicated airspeed. The lead aircraft, NWA4091 was a DC9 and although the aircraft WILCO'ed the Data Comm message, the aircraft could not meet the 320 knots indicated airspeed or greater requirement. When the controller noticed the overtake situation because it now has become a tactical situation, he should have called the pilot and verify the speed and make a correction via voice communications if necessary.

Start	ACID	Task	Modality	Content	Position
00:18:07.773	NWA4091	ERROR	nas	NWA4091 /NWA4091	R-side
00:18:11.000	AAL1889	HandoffAccept	nas	AAL1889	R-side
00:18:13.000	AAL1889	DragLabel	nas	no_data_found	R-side
00:18:14.775	NWA4091	DragLabel	nas	no_data_found	R-side
00:18:16.396	NWA4091	HandoffAccept	nas	NWA4091	R-side
00:18:16.874	NWA4091	HandoffAccept	nas	NWA4091	R-side
00:18:50.000	NWA4091	MonitorFrequency	datalink	CC 120080	Pilot
00:19:01.622	NWA4091	MacroTearoffButton1	datalink	QU LANCE DL: NWA4091	R-side
00:19:15.000	AAL1889	MonitorFrequency	datalink	CC 120080	Pilot
00:19:33.000	NWA4091	DirectToFix	datalink	DIR LANCE;	Pilot
00:21:08.294	NWA4091	LeaderChangeRequest	nas	4 190	R-side
00:22:00.928	AAL1889	ERROR	nas	QP J 700	R-side
00:23:02.290	NWA4091	DragLabel	nas	no_data_found	R-side
00:24:41.619	NWA4091	MacroTearoffButton5	nas	XC LANCE 280 DL:22: NWA4091	R-side
00:24:44.638	NWA4091	QSL	datalink	QS /320+ S NWA4091	R-side
00:25:24.000	NWA4091	ChangeSpeed	datalink	S320	Pilot
00:25:30.000	NWA4091	CrossFixAtAltitude	datalink	CRS LANCE A280	Pilot
00:25:53.342	AAL1889	MacroTearoffButton9	datalink	QU LANCE DL:XC LANCE 280 DL:22: AAL1889	R-side
00:25:58.456	AAL1889	QSL	datalink	QS /310- S AAL1889	R-side
00:26:23.000	AAL1889	DirectToFix CrossFixAtAltitude	datalink	DIR LANCE;; CRS LANCE	Pilot
00:26:23.974	NWA4091	LeaderChangeRequest	nas	8 190	R-side
00:26:27.397	AAL1889	LeaderChangeRequest	nas	7 700	R-side
00:26:29.705	AAL1889	LeaderChangeRequest	nas	/5 700	R-side
00:26:38.000	AAL1889	ChangeSpeed	datalink	S310	Pilot
00:26:54.150	NWA4091	ButtonRelease	nas	no_data_found	R-side
00:26:56.527	AAL1889	DragLabel	nas	no_data_found	R-side
00:26:59.497	no_acid_found	ERROR	nas	NWA4091 6 190	R-side
00:27:02.232	NWA4091	HandoffAccept	nas	190	R-side
00:27:03.789	NWA4091	HandoffRequest	nas	22 190	R-side

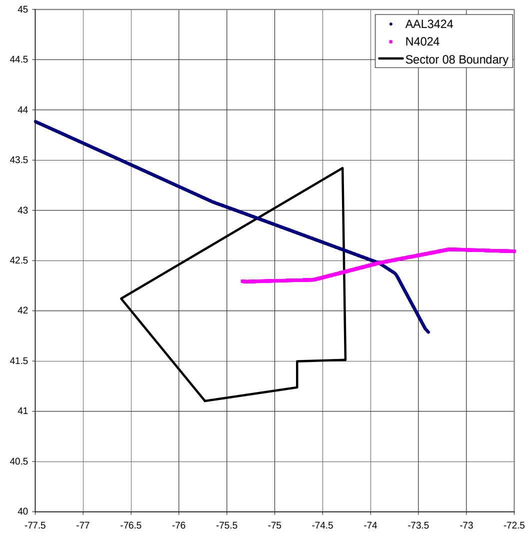

AAL1889
NWA4091
Sector 08 Boundary
45
44.5
44
43.5
43
42.5
42
41.5
41
40.5
40
-77.5
-77
-76.5
-76
-75.5
-75
-74.5
-74
-73.5
-73
-72.5


AAL1889
NWA4091
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0:00:00
0:05:00
0:10:00
0:15:00
0:20:00
0:25:00
0:30:00
0:35:00
0:40:00
0:45:00
0:50:00

Proximity Incident #3 between AAL3424 and N4024 (T06FGN1d100_050R02)

Both aircraft were in sector 07's airspace. Sector 01 had taken the handoff on AAL3424 descending it to 140 while 08 accepted N4024. Separation was lost by AAL3424 catching the backend of N4024.

Start	ACID	Task	Modality	Content	Position
00:32:45.356	AAL3424	HandoffAccept	nas	AAL3424	D-side
00:33:36.000	AAL3424	MonitorFrequency	DataLink	CC 120080	Pilot
00:35:24.000	N4024	MonitorFrequency	DataLink	CC 120070	Pilot
00:35:37.350	AAL3424	ControllerDisplayInteraction	nas	no_data_found	D-side
00:35:39.156	AAL3424	DragLabel	nas	no_data_found	D-side
00:36:21.158	AAL3424	QQ	datalink	QQ 340 411 DL	D-side
00:37:00.000	AAL3424	ChangeAltitudeTo	DataLink	A340	Pilot
00:37:00.416	AAL3424	MacroTearoffButton3	nas	QP J : AAL3424	D-side
00:39:15.485	AAL3424	QQ	datalink	QQ /OK 411 DL	D-side
00:39:23.189	AAL3424	QQ	nas	QQ /OK 240 411	D-side
00:39:28.702	AAL3424	QP	nas	QP J AAL3424	R-side
00:39:31.000	AAL3424	ChangeAltitudeTo	nas	A240	Pilot
00:39:45.000	AAL3424	ChangeAltitudeTo	DataLink	A350	Pilot
00:40:06.658	AAL3424	MacroTearoffButton8	nas	UH:/0: AAL3424	D-side
00:40:34.232	N4024	HandoffAccept	nas	N4024	R-side
00:41:05.000	AAL3424	MonitorFrequency	DataLink	CC 120070	Pilot
00:41:43.000	N4024	MonitorFrequency	DataLink	CC 120080	Pilot
00:42:27.000	AAL3424	MonitorFrequency	DataLink	CC 120010	Pilot
00:43:30.755	AAL3424	DROP-FDB	nas	AAL3424	R-side
00:43:31.238	AAL3424	DROP-ADB	nas	AAL3424	R-side
00:44:35.198	N4024	MacroTearoffButton2	nas	no_data_found	D-side
00:47:39.000	AAL3424	MonitorFrequency	DataLink	CC 120150	Pilot
00:48:21.000	N4024	RequestRoute	DataLink	DL RTE DES NEV	Pilot
00:48:58.529	N4024	ControllerDisplayInteraction	nas	no_data_found	D-side
00:50:10.000	N4024	ClearedRoute	DataLink	DIR DES NEV;	Pilot


AAL3424
N4024
Sector 08 Boundary
45
44.5
44
43.5
43
42.5
42
41.5
41
40.5
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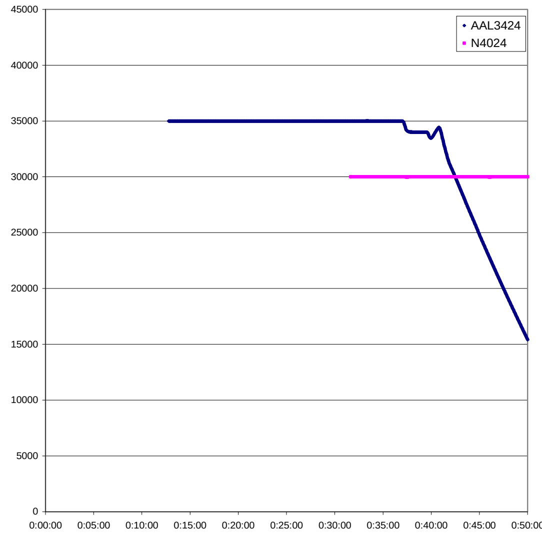
-72.5


AAL3424
N4024
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15000
10000
5000
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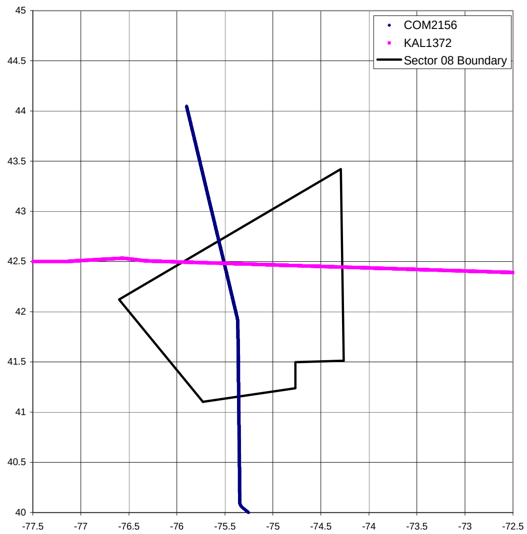
0:40:00
0:45:00
0:50:00

Proximity Incident #4 between COM2156 and KAL1372 (T08FCP1b100_050R12)

COM2156 was descended to FL330 with an interim from FL370. At about 11:30 the interim was changed to FL340 but it was only a NAS update message. Have to check voice to see if the controller told the aircraft to stop the descent at FL330. Somehow COM2156 handed off to sector 01 and 01 immediately accepted the handoff. The controller DID use voice and instructed the pilot to stop amend the altitude to FL340. Have to check if the pilot entered it and if the Data Comm message overwrote the voice command.

Start	End	ACID	Task	Modality	Content	Position
00:07:18.454	00:07:58.776	COM2156	ERROR	nas	COM2156 /COM2156	R-side
00:07:34.434	00:07:34.576	KAL1372	HandoffAccept	nas	KAL1372	D-side
00:07:58.674	00:07:58.867	COM2156	HandoffAccept	nas	COM2156	D-side
00:08:00.553	00:08:00.776	COM2156	ControllerCommand	nas	COM2156	R-side
00:08:10.685	00:08:10.925	COM2156	ControllerCommand	nas	COM2156	D-side
00:08:22.198	00:08:24.624	COM2156	LeaderChangeRequest	nas	4 299	R-side
00:08:38.540	00:08:39.977	COM2156	LF	nas	LF COM2156 LANCE	D-side
00:09:05.693	00:09:07.515	KAL1372	MacroTearoffButton5	nas	QU NJY: KAL1372	D-side
00:09:07.000		KAL1372		nas	DIR NJY	Pillot
00:09:25.000		COM2156		datalink	CC 120080	Pillot
00:10:53.815	00:10:57.288	COM2156	QQ	datalink	QQ 330 S COM2156	D-side
00:11:21.134	00:11:24.736	COM2156	QQ	nas	QQ 340 COM2156	D-side
00:11:32.000		COM2156		nas	A340	Pillot
00:11:35.000		COM2156		datalink	A330	Pillot
00:11:54.807	00:11:54.908	COM2156	DragLabel	nas	no_data_found	D-side
00:11:54.988	00:11:55.073	COM2156	ToggleDwellLock	nas	no_data_found	D-side
00:12:38.942	00:12:40.598	COM2156	DragLabel	nas	no_data_found	R-side
00:13:19.000		COM2156		nas	A340	Pillot
00:13:36.000		COM2156		nas	E280	Pillot
00:13:39.005	00:13:39.554	KAL1372	ABORTEDCMD	nas	KAL1372	D-side
00:13:39.632	00:13:42.414	KAL1372	QZ	nas	QZ 350 KAL1372	D-side
00:13:43.352	00:13:45.160	COM2156	LeaderChangeRequest	nas	9 COM2156	D-side
00:13:44.000		KAL1372		nas	A350	Pillot
00:13:52.000		KAL1372		nas	E350	Pillot
00:13:59.523	00:14:06.785	COM2156	QQ	datalink	QQ /OK 280 S COM2156	D-side
00:14:03.736	00:14:03.923	COM2156	UH	nas	UH COM2156	R-side
00:14:09.916	00:14:13.904	COM2156	ToggleLabelPositionAlgo	nas	/OK COM2156	R-side
00:14:26.092	00:14:31.113	KAL1372	LeaderChangeRequest	nas	2 KAL1372	R-side
00:14:30.540	00:14:31.499	COM2156	HandoffRequest	nas	22 COM2156	D-side
00:14:33.000		COM2156		datalink	CC 120010	Pillot
00:14:46.622	00:15:10.968	COM2156	QP__ControllerCommand_	nas	QP COA2143 /SKW1556	R-side
00:14:46.752	00:14:49.467	KAL1372	HandoffRequest	nas	07 UAL2694 /KAL1372	D-side
00:14:48.000		COM2156		datalink	A280	Pillot
00:15:15.424	00:15:15.496	COM2156	DragLabel	nas	no_data_found	D-side
00:15:15.568	00:15:15.661	COM2156	ToggleDwellLock	nas	no_data_found	D-side
00:18:19.137	00:18:21.461	KAL1372	LeaderChangeRequest	nas	/0 KAL1372	D-side
00:18:25.434	00:18:26.551	COM2156	LeaderChangeRequest	nas	4 COM2156	D-side
00:18:28.000		KAL1372		nas	CC 120.07	Pillot
00:21:53.281	00:21:54.444	KAL1372	MacroTearoffButton1	nas	QP : KAL1372	D-side
00:22:52.878	00:22:53.838	COM2156	LeaderChangeRequest	nas	/0 COM2156	D-side
00:24:54.578	00:24:58.326	COM2156	DROP-FDB	nas	COM2156	R-side
00:24:59.120	00:24:59.304	COM2156	DROP-ADB	nas	COM2156	R-side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KAL1372
Sector 08 Boundary
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44.5
44
43.5
43
42.5
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41.5
41
40.5
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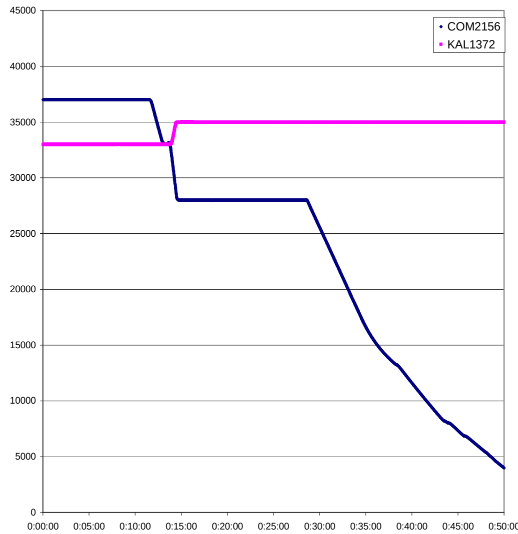
-72.5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KAL1372
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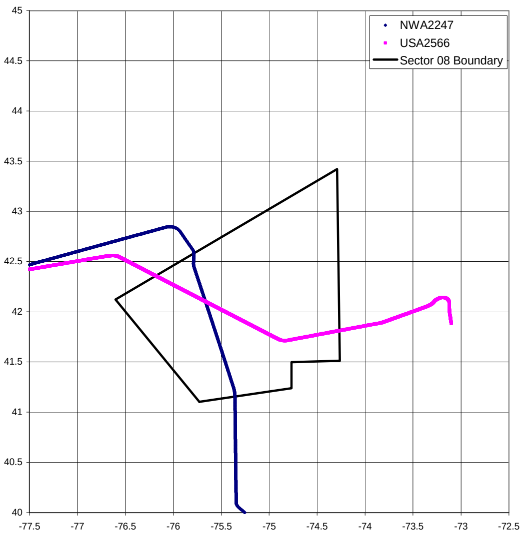
0:35:00
0:40:00
0:45:00
0:50:00

Proximity Incident # 5 between USA2566 and NWA2247 (T09FCN1d100_050R04)

Conflict alert did not activate. USA2566 was climbing to FL350 and caught NWA2247 on the backend on its way down from FL300 to FL280. Conflict alert had gone off earlier when NWA2247 was level at FL310.

Start	ACID	Task	Modality	Content	Position
00:01:45.000	NWA2247		datalink	CC 120330	Pilot
00:10:52.000	USA2566		datalink	CC 120010	Pilot
00:12:57.000	NWA2247		datalink	CC 120020	Pilot
00:14:49.000	USA2566		datalink	CC 120070	Pilot
00:18:13.000	USA2566		datalink	CC 120080	Pilot
00:20:14.797	USA2566	ERROR	nas	85 USA2566	D-side
00:20:19.814	USA2566	LeaderChangeRequest	nas	8 USA2566	D-side
00:20:28.169	USA2566	QQ	datalink	QQ 300 S USA2566	D-side
00:20:38.189	USA2566	ABORTEDCMD	nas	no_data_found	R-side
00:20:40.005	USA2566	QZ	datalink	QZ 360 S USA2566	R-side
00:21:14.000	USA2566		datalink	A300	Pilot
00:22:02.893	USA2566	LeaderChangeRequest	nas	2 613	R-side
00:22:04.688	USA2566	DisplayForwardRoutePath	nas	QU 99 613	R-side
00:22:11.118	USA2566	DisplayForwardRoutePath	nas	QU 99 613	R-side
00:22:14.289	USA2566	FlightPlanReadout	nas	QF 613	R-side
00:22:18.255	USA2566	ControllerCommand	nas	QU DSM EUG 613 DL	R-side
00:22:29.527	USA2566	FlightPlanReadout	nas	QF 613	R-side
00:23:10.990	USA2566	ModifyRoute	datalink	QU DES EUG 613 DL	R-side
00:23:24.320	NWA2247	HandoffAccept	nas	562	R-side
00:23:24.893	NWA2247	ControllerCommand	nas	NWA2247	D-side
00:23:42.000	USA2566		datalink	DIR DES EUG;	Pilot
00:23:58.650	USA2566	LeaderChangeRequest	nas	4 613	R-side
00:24:15.000	NWA2247		datalink	CC 120080	Pilot
00:25:40.624	NWA2247	ToggleForwardRoutePath	nas	QU 562	R-side
00:25:44.832	NWA2247	ModifyRoute	nas	QU LANCE 562	R-side
00:25:51.000	NWA2247		nas	DIR LANCE	Pilot
00:26:10.786	USA2566	LeaderChangeRequest	nas	8 613	D-side
00:27:38.378	NWA2247	QZ	nas	QZ 300 562	R-side
00:27:46.000	NWA2247		nas	A300	Pilot
00:27:50.337	USA2566	QZ	datalink	QZ 360 S USA2566	R-side
00:28:28.000	USA2566		datalink	A360	Pilot
00:28:34.865	NWA2247	QQ	datalink	QQ 280 S NWA2247	D-side
00:29:06.440	no_acid_found	CO	nas	CO NWA2247/USA2566	D-side
00:29:21.000	NWA2247		datalink	A280	Pilot
00:29:33.103	NWA2247	DragLabel	nas	no_data_found	D-side
00:29:35.156	USA2566	DragLabel	nas	no_data_found	D-side
00:29:36.828	USA2566	LeaderChangeRequest	nas	4 613	R-side
00:31:28.036	TRS2775	HandoffAccept	nas	TRS2775	D-side
00:32:11.197	NWA2247	LeaderChangeRequest	nas	1 NWA2247	D-side
00:33:10.694	NWA2247	UH	nas	UH NWA2247	R-side
00:33:11.484	NWA2247	LeaderChangeRequest	nas	7 562	R-side
00:33:19.413	USA2566	DROP-FDB	nas	USA2566	D-side
00:33:19.911	USA2566	DROP-ADB	nas	USA2566	D-side
00:33:50.000	NWA2247		datalink	CC 120220	Pilot
00:36:25.114	NWA2247	Drop-FDB	nas	562	D-side
00:36:26.181	NWA2247	Drop-ADB	nas	562	D-side
00:41:49.000	NWA2247		datalink	CC 120180	Pilot
00:44:49.000	NWA2247		datalink	CC 123400	Pilot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USA2566
Sector 08 Boundary
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44.5
44
43.5
43
42.5
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41.5
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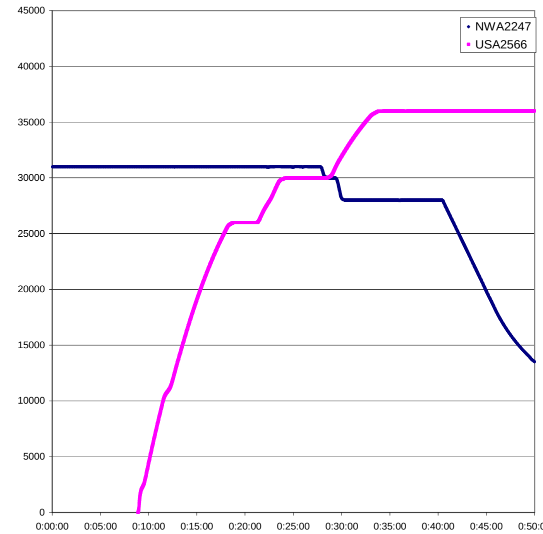
-72.5


NWA2247
USA2566
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20000
15000
10000
5000
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0:30:00
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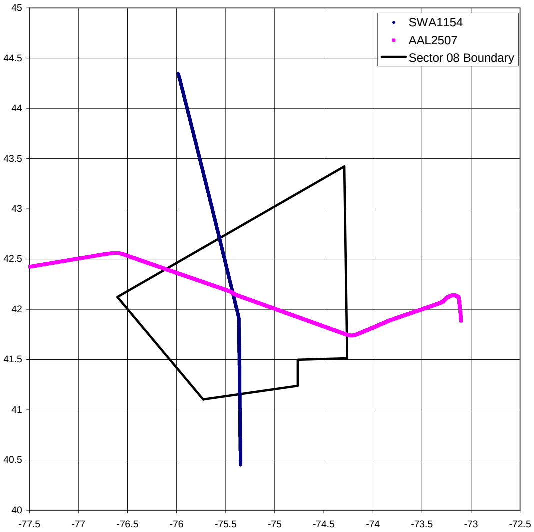
0:40:00
0:45:00

Proximity Incident # 6 between SWA1154 and AAL2507 (T09FCN1l100_100R09)

Controller uses a 40R heading over Data Comm to maneuver behind the SWA1154 but catches the backend. Controllers realized that it was going to be close, but decided not to use voice.

Start	ACID	Task	Modality	Content	Position
00:19:50.000	AAL2507		datalink	CC 120010	Pilot
00:21:53.466	SWA1154	FORCE-FDB	nas	SWA1154	D-side
00:21:55.998	SWA1154	LF	nas	LF SWA1154 LANCE	D-side
00:24:01.000	AAL2507		datalink	CC 120070	Pilot
00:25:54.901	AAL2507	HandoffAccept	nas	AAL2507	D-side
00:25:54.921	AAL2507	LeaderChangeRequest	nas	8 AAL2507	R-side
00:27:26.000	AAL2507		datalink	CC 120080	Pilot
00:27:46.986	AAL2507	QZ	datalink	QZ 300 S AAL2507	D-side
00:27:52.287	AAL2507	ModifyRoute	datalink	QU DES EUG 402 DL	D-side
00:28:06.435	AAL2507	LeaderChangeRequest	nas	2 402	D-side
00:28:30.487	SWA1154	LeaderChangeRequest	nas	4 628	R-side
00:28:31.000	AAL2507		datalink	A300	Pilot
00:28:40.926	SWA1154	HandoffAccept	nas	SWA1154	D-side
00:28:45.000	AAL2507		datalink	DIR DES EUG;	Pilot
00:29:09.000	SWA1154		datalink	CC 120080	Pilot
00:34:20.106	SWA1154	LeaderChangeRequest	nas	2 628	R-side
00:35:28.897	SWA1154	QP	nas	QP J 628	R-side
00:35:31.549	SWA1154	QZ	datalink	QZ 280 S SWA1154	R-side
00:35:39.666	AAL2507	DLSpeedPopupInteraction	nas	no_data_found	R-side
00:35:45.417	AAL2507	QS	datalink	QS 40R S AAL2507	R-side
00:35:56.531	SWA1154	DragLabel	nas	no_data_found	R-side
00:36:02.000	SWA1154		datalink	A280	Pilot
00:36:21.140	AAL2507	QF	nas	QF 402	R-side
00:36:42.046	SWA1154	QP	nas	QP J 628	R-side
00:36:46.038	AAL2507	ModifyRoute	datalink	QU DES S AAL2507	R-side
00:36:55.000	AAL2507		datalink	R+40	Pilot
00:37:10.000	AAL2507		datalink	DIR DES;	Pilot
00:37:26.787	AAL2507	HandoffRequest	nas	02 402	R-side
00:38:34.897	SWA1154	HandoffRequest	nas	22 628	R-side
00:38:39.987	AAL2507	UH	nas	UH AAL2507	D-side
00:39:09.000	AAL2507		datalink	CC 120020	Pilot
00:39:22.297	SWA1154	LeaderChangeRequest	nas	6 628	D-side
00:41:34.666	SWA1154	UH	nas	UH SWA1154	D-side
00:42:11.000	SWA1154		datalink	CC 120220	Pilot
00:43:19.238	AAL2507	DROP-FDB	nas	402	R-side
00:43:20.300	AAL2507	DROP-ADB	nas	402	R-side
00:44:09.645	SWA1154	DROP-FDB	nas	628	R-side
00:44:10.611	SWA1154	DROP-ADB	nas	628	R-side
00:45:40.000	AAL2507		datalink	CC 120330	Pilot
00:50:04.000	SWA1154		datalink	CC 120180	Pilot



SWA1154
AAL2507
Sector 08 Boundary
45
44.5
44
43.5
43
42.5
42
41.5
41
40.5
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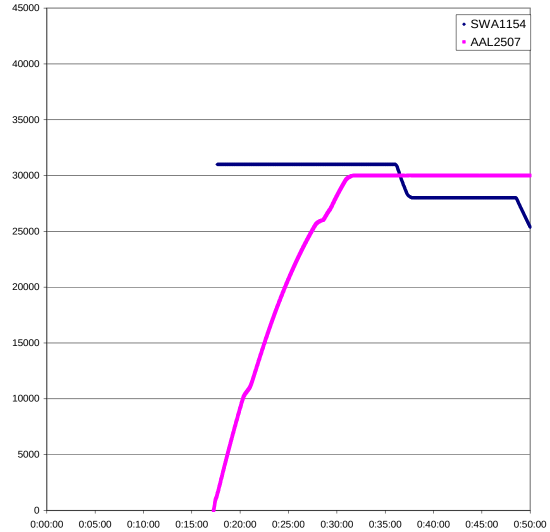
-72.5



SWA1154
AAL2507
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0:00:00
0:05:00
0:10:00
0:15:00
0:20:00
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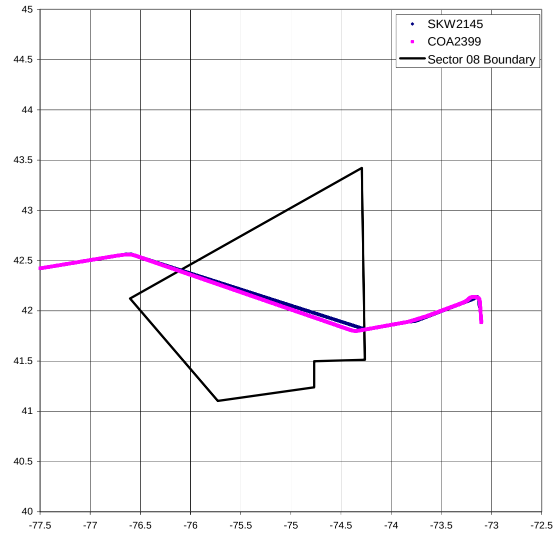
0:30:00
0:35:00
0:40:00
0:45:00
0:50:00

Proximity Incident # 7 between SKW2145 and COA2399 (T10FCN1f100_050R04)

Conflict Alert did not activate. Overtake situation. The SKW2145 is slow at 246 knots and the COA2399 runs over the aircraft climbing to FL340.

Start	ACID	Task	Modality	Content	Position
00:01:34.000	SKW2145	MonitorFrequency	datalink	CC 120010	Pilot
00:07:23.000	SKW2145	MonitorFrequency	datalink	CC 120070	Pilot
00:11:39.000	COA2399	MonitorFrequency	datalink	CC 120010	Pilot
00:13:41.192	SKW2145	HandoffAccept	nas	SKW2145	R-side
00:14:57.000	SKW2145	MonitorFrequency	datalink	CC 120080	Pilot
00:15:21.896	SKW2145	QZ	datalink	QZ 280 S SKW2145	D-side
00:15:26.000	COA2399	MonitorFrequency	datalink	CC 120070	Pilot
00:15:32.216	SKW2145	ABORTEDCMD	nas	no_data_found	D-side
00:15:52.073	SKW2145	ToggleForwardRoutePath	nas	QU F SKW2145	R-side
00:15:53.842	SKW2145	ModifyRoute	datalink	QU DES EUG 020 DL	R-side
00:16:17.000	SKW2145	ModifyAltitude	datalink	A280	Pilot
00:16:33.000	SKW2145	ModifyRoute	datalink	DIR DES EUG;	Pilot
00:17:29.628	SKW2145	ToggleForwardRoutePath	nas	QU 020	D-side
00:18:04.930	COA2399	HandoffAccept	nas	COA2399	R-side
00:18:24.495	COA2399	QF	nas	QF COA2399	R-side
00:18:34.844	SKW2145	QZ	nas	QZ 320 020	D-side
00:18:45.000	SKW2145	ModifyAltitude	nas	A320	Pilot
00:19:25.860	SKW2145	LeaderChangeRequest	nas	8 020	D-side
00:19:29.247	SKW2145	ToggleForwardRoutePath	nas	QU 020	D-side
00:19:34.000	COA2399	MonitorFrequency	datalink	CC 120080	Pilot
00:19:59.847	SKW2145	ToggleForwardRoutePath	nas	QU 020	R-side
00:20:43.037	COA2399	LeaderChangeRequest	nas	3 349	D-side
00:20:44.981	COA2399	ToggleForwardRoutePath	nas	QU 349	D-side
00:21:10.861	COA2399	ModifyRoute	datalink	QU DES EUG 349 DL	R-side
00:21:22.629	SKW2145	ControllerDisplayInteraction	nas	no_data_found	R-side
00:21:30.962	COA2399	QZ	datalink	QZ 340 S COA2399	R-side
00:22:00.000	COA2399	ModifyRoute	datalink	DIR DES EUG;	Pilot
00:22:09.465	COA2399	LeaderChangeRequest	nas	8 349	D-side
00:22:13.382	SKW2145	LeaderChangeRequest	nas	2 020	D-side
00:22:16.000	COA2399	ModifyAltitude	datalink	A340	Pilot
00:27:01.514	COA2399	LeaderChangeRequest	nas	6 349	D-side
00:27:44.326	COA2399	HandoffRequest	nas	02 349	R-side
00:30:08.893	COA2399	LeaderChangeRequest	nas	9 COA2399	R-side
00:30:56.374	COA2399	ControllerCommand	nas	QU P Y COA2399	R-side
00:30:59.952	SKW2145	LeaderChangeRequest	nas	6 020	R-side
00:31:03.335	COA2399	LeaderChangeRequest	nas	8 349	R-side
00:31:15.154	SKW2145	UH	nas	UH SKW2145	D-side
00:31:16.368	SKW2145	LeaderChangeRequest	nas	/0 020	D-side
00:31:20.937	COA2399	UH	nas	UH COA2399	D-side
00:31:47.000	SKW2145	MonitorFrequency	datalink	CC 120010	Pilot
00:32:02.000	COA2399	MonitorFrequency	datalink	CC 120020	Pilot
00:32:09.919	COA2399	LeaderChangeRequest	nas	/0 349	D-side
00:34:33.821	SKW2145	LeaderChangeRequest	nas	4 020	D-side
00:34:35.576	COA2399	LeaderChangeRequest	nas	4 349	D-side
00:34:37.364	COA2399	DROP-FDB	nas	349	D-side
00:34:47.425	COA2399	DROP-ADB	nas	COA2399	R-side
00:35:52.000	SKW2145	MonitorFrequency	datalink	CC 120020	Pilot
00:37:37.933	SKW2145	DROP-FDB	nas	SKW2145	R-side
00:38:10.000	COA2399	MonitorFrequency	datalink	CC 120330	Pilot
00:39:11.623	SKW2145	DROP-ADB	nas	SKW2145	R-side
00:42:55.000	SKW2145	MonitorFrequency	datalink	CC 120330	Pilot
00:49:20.000	COA2399	MonitorFrequency	datalink	CC 120060	Pilot



SKW2145
COA2399
Sector 08 Boundary
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44.5
44
43.5
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42.5
42
41.5
41
40.5
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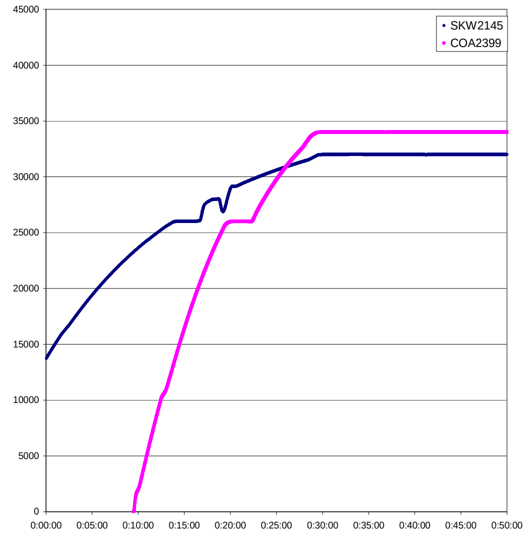
-72.5



SKW2145
COA2399
45000
40000
35000
30000
25000
20000
15000
10000
5000
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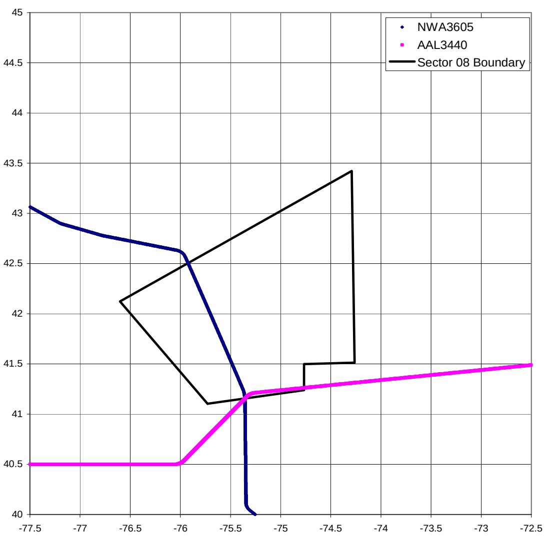
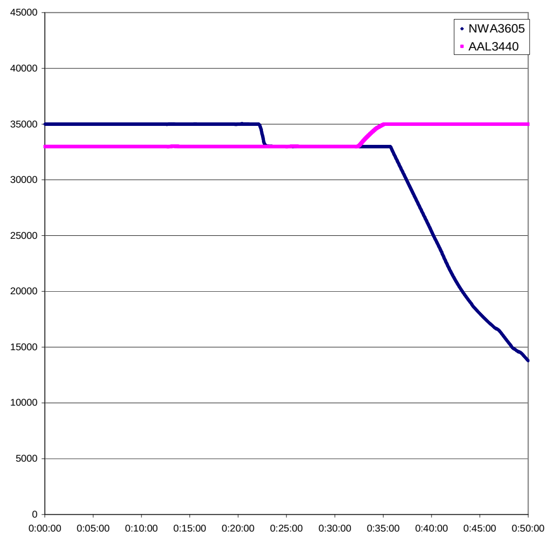
0:50:00

Proximity Incident # 8 between NWA3605 and AAL3440 (T10FCN1n100_100R07)

Keyboard entry of FL280 (not a Data Comm message) on NWA3605, but aircraft never descends. Have to check the audio if the pilot received a clearance to descend.

Start	ACID	Task	Modality	Content	Position
00:17:54.334	NWA3605	HandoffAccept	nas	NWA3605	R-side
00:18:47.592	NWA3605	ABORTEDCMD	nas	no_data_found	D-side
00:18:59.883	NWA3605	ModifyRoute	datalink	QU LANCE S NWA3605	D-side
00:19:00.000	NWA3605	MonitorFrequency	datalink	CC 120080	Pilot
00:19:21.855	NWA3605	LeaderChangeRequest	nas	6 190	D-side
00:19:35.000	NWA3605	ModifyRoute	datalink	DIR LANCE;	Pilot
00:20:32.824	NWA3605	QP	nas	QP J 190	D-side
00:21:41.308	NWA3605	QZ	datalink	QZ 330 190 DL	D-side
00:22:06.000	NWA3605	ModifyAltitude	datalink	A330	Pilot
00:22:48.356	NWA3605	LeaderChangeRequest	nas	4 190	D-side
00:23:32.000	AAL3440	MonitorFrequency	datalink	CC 120330	Pilot
00:24:08.810	NWA3605	LeaderChangeRequest	nas	1 190	D-side
00:24:10.988	NWA3605	LeaderChangeRequest	nas	6 190	D-side
00:25:48.987	NWA3605	QQ	nas	QQ 280 190	D-side
00:25:51.000	AAL3440	MonitorFrequency	datalink	CC 120220	Pilot
00:26:33.764	NWA3605	HandoffRequest	nas	22 190	R-side
00:27:41.423	NWA3605	QP	nas	QP J 190	R-side
00:28:19.664	AAL3440	HandoffAccept	nas	AAL3440	R-side
00:29:10.028	NWA3605	UH	nas	UH NWA3605	D-side
00:29:28.000	AAL3440	MonitorFrequency	datalink	CC 120080	Pilot
00:29:52.000	NWA3605	MonitorFrequency	datalink	CC 120220	Pilot
00:30:14.660	AAL3440	LeaderChangeRequest	nas	8 802	D-side
00:30:24.557	NWA3605	LeaderChangeRequest	nas	/0 190	D-side
00:30:27.093	AAL3440	LeaderChangeRequest	nas	4 802	D-side
00:31:06.577	NWA3605	LeaderChangeRequest	nas	4 190	D-side
00:31:08.926	AAL3440	LeaderChangeRequest	nas	9 802	D-side
00:31:25.284	AAL3440	ModifyRoute	datalink	QU NJY S AAL3440	D-side
00:31:30.957	AAL3440	QZ	datalink	QZ 350 S AAL3440	D-side
00:32:03.000	AAL3440	ModifyRoute	datalink	DIR NJY;	Pilot
00:32:10.680	NWA3605	DROP-FDB	nas	190	D-side
00:32:14.570	AAL3440	LeaderChangeRequest	nas	8 802	D-side
00:32:16.000	AAL3440	ModifyAltitude	nas	A350	Pilot
00:32:18.000	AAL3440	ModifyAltitude	datalink	A350	Pilot
00:33:14.850	AAL3440	HandoffRequest	nas	22 802	D-side
00:33:29.857	AAL3440	UH	nas	UH AAL3440	R-side
00:33:30.863	AAL3440	LeaderChangeRequest	nas	/0 AAL3440	R-side
00:33:58.000	AAL3440	MonitorFrequency	datalink	CC 120220	Pilot
00:36:52.000	AAL3440		datalink	CC 120070	Pilot
00:38:24.096	AAL3440	MonitorFrequency	nas	AAL3440	R-side
00:38:24.340	AAL3440	DROP-ADB	nas	AAL3440	R-side
00:39:45.000	NWA3605	MonitorFrequency	datalink	CC 120180	Pilot
00:45:05.000	NWA3605	MonitorFrequency	datalink	CC 123400	Pilot
00:49:45.000	AAL3440	MonitorFrequency	datalink	CC 120140	Pilot

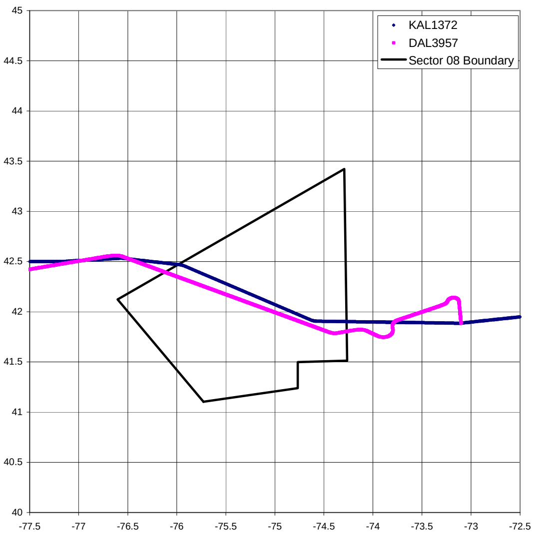

NWA3605
AAL3440
Sector 08 Boundary
45
44.5
44
43.5
43
42.5
42
41.5
41
40.5
40
-77.5
-77
-76.5
-76
-75.5
-75
-74.5
-74
-73.5
-73
-72.5


NWA3605
AAL3440
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0:00:00
0:05:00
0:10:00
0:15:00
0:20:00
0:25:00
0:30:00
0:35:00
0:40:00
0:45:00
0:50:00

Proximity Incident # 9 between DAL3957 and KAL1372 (T13FTN1b100_050R02)

Conflict Alert did not activate. Tried to climb DAL3957 to FL340

Start	ACID	Task	Modality	Content	Position
00:02:32.000	DAL3957	MoniitorFreqency	datalink	CC 120010	Pilot
00:06:34.000	DAL3957	MoniitorFreqency	datalink	CC 120070	Pilot
00:07:49.623	KAL1372	HandoffAccept	nas	259	R-side
00:07:50.951	KAL1372	LeaderChangeRequest	nas	2 259	R-side
00:10:03.084	DAL3957	HandoffAccept	nas	182	R-side
00:10:34.159	DAL3957	QF	nas	QF DAL3957	D-side
00:10:59.000	DAL3957	MoniitorFreqency	datalink	CC 120080	Pilot
00:11:11.721	DAL3957	ControllerDisplayInteraction	nas	no_data_found	D-side
00:11:25.812	DAL3957	QZ	datalink	QZ 340 S DAL3957	D-side
00:11:55.000	DAL3957	ModifyAltitude	datalink	A340	Pilot
00:12:07.725	KAL1372	LeaderChangeRequest	nas	8 259	R-side
00:12:34.664	DAL3957	ToggleForwardRoutePath	nas	QU F DAL3957	D-side
00:12:35.347	DAL3957	ToggleForwardRoutePath	nas	QU F DAL3957	D-side
00:12:52.177	DAL3957	ControllerDisplayInteraction	nas	no_data_found	D-side
00:12:58.638	DAL3957	ControllerDisplayInteraction	nas	no_data_found	D-side
00:13:06.544	DAL3957	MacroTearoffButton45	datalink	QU DES EUG DL: DAL3957	D-side
00:13:10.827	DAL3957	ControllerCommand	nas	DAL3957	D-side
00:13:23.223	KAL1372	HandoffRequest	nas	07 KAL1372	D-side
00:13:44.000	DAL3957	ModifyRoute	datalink	DIR DES EUG;	Pilot
00:13:57.834	KAL1372	QP	nas	QP J 259	R-side
00:14:24.003	KAL1372	LeaderChangeRequest	nas	2 259	R-side
00:14:49.509	KAL1372	QP	nas	QP J 259	R-side
00:15:36.720	DAL3957	LeaderChangeRequest	nas	8 182	R-side
00:17:34.889	DAL3957	HandoffRequest	nas	02 DAL3957	D-side
00:19:21.852	KAL1372	LeaderChangeRequest	nas	4/0 KAL1372	R-side
00:19:27.000	KAL1372	ContactController	nas	CC 120.070	Pilot
00:20:50.261	DAL3957	LeaderChangeRequest	nas	2 182	R-side
00:21:13.293	KAL1372	QP	nas	QP 259	R-side
00:23:27.145	DAL3957	MacroTearoffButton42	nas	UH:/0: DAL3957	D-side
00:23:55.000	DAL3957	MoniitorFreqency	datalink	CC 120020	Pilot
00:25:46.144	DAL3957	DROP-FDB	nas	DAL3957	D-side
00:25:46.943	DAL3957	DROP-ADB	nas	DAL3957	D-side
00:30:05.000	DAL3957	MoniitorFreqency	datalink	CC 120330	Pilot
00:41:42.000	DAL3957	MoniitorFreqency	datalink	CC 120060	Pilot



KAL1372
DAL3957
Sector 08 Boundary
45
44.5
44
43.5
43
42.5
42
41.5
41
40.5
40
-77.5
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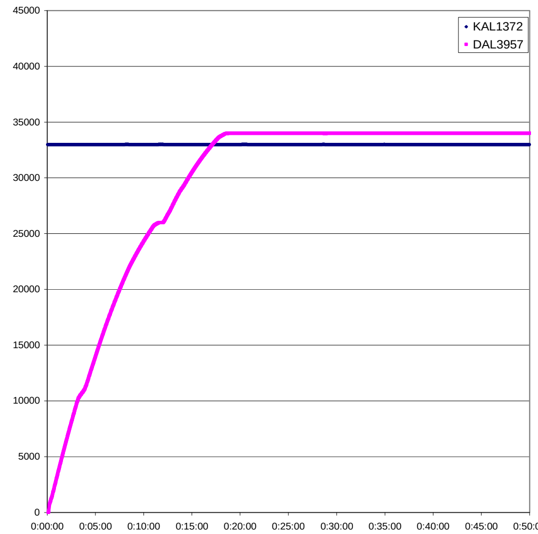
-73.5
-73
-72.5

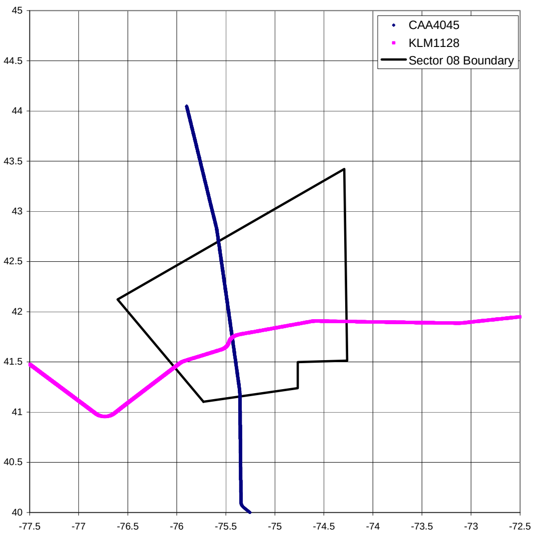


KAL1372
DAL3957
45000
40000
35000
30000
25000
20000
15000
10000
5000
0
0:00:00
0:05:00
0:10:00
0:15:00
0:20:00
0:25:00
0:30:00
0:35:00
0:40:00
0:45:00

Proximity Incident # 10 between CAA4045 and KLM1128 (T13FCN1l100_100R08)

Conflict Alert initially activated, aircraft then showed level at FL340 and FL350. Controller gave a crossing restriction to CAA4045 which showed Mode C at FL342. CA but was no longer active at the LoS.

Start	ACID	Task	Modality	Content	Position
00:08:05.241	CAA4045	HandoffAccept	nas	299	R-side
00:08:16.173	CAA4045	LF	nas	LF 299 LANCE	R-side
00:09:41.000	CAA4045	MonitorFrequency	datalink	CC 120080	Pilot
00:09:58.614	CAA4045	MacroTearoffButton5	datalink	QU LANCE DL: CAA4045	R-side
00:10:28.000	CAA4045	ModifyRoute	datalink	DIR LANCE;	Pilot
00:13:53.770	KLM1128	HandoffAccept	nas	KLM1128	R-side
00:15:03.000	KLM1128	MonitorFrequency	datalink	CC 120080	Pilot
00:16:30.231	CAA4045	QZ	datalink	QZ 340:XC 280:AT LANCE:QS /310:CAA4045 DL	R-side
00:17:40.000	CAA4045	ModifyAltitude; ModfiySpeed	datalink	A340; S310	Pilot
00:18:01.408	CAA4045	XC	datalink	XC 280:AT LANCE:QZ 340:QS /310:CAA4045 DL	R-side
00:18:31.785	CAA4045	LeaderChangeRequest	nas	6 299	D-side
00:19:14.000	CAA4045	ModifyAltitude; ModfiySpeed	datalink	A340; S310	Pilot
00:19:40.562	KLM1128	ToggleForwardRoutePath	nas	QU 303	R-side
00:19:44.322	KLM1128	ModifyRoute	datalink	QU 4144/07535 CIN: KLM1128 DL	R-side
00:19:50.062	CAA4045	QP	nas	QP J 299	R-side
00:20:17.000	KLM1128	ModifyRoute	datalink	DIR 4144/07535 CIN;	Pilot
00:20:25.375	CAA4045	HandoffAccept	nas	299	R-side
00:20:27.744	CAA4045	MacroTearoffButton6	nas	XC LANCE 280 DL:22: CAA4045	R-side
00:20:54.192	CAA4045	QP	nas	QP J 299	R-side
00:21:02.000	CAA4045	CrossFixAtAltitude	datalink	CRS LANCE A280	Pilot
00:21:18.328	KLM1128	LeaderChangeRequest	nas	2 303	R-side
00:21:25.330	CAA4045	LeaderChangeRequest	nas	4 299	R-side
00:21:39.280	CAA4045	MacroTearoffButton2	nas	UH:/0: TRS2537 /DAL3378 /CAA4045	D-side
00:21:48.639	KLM1128	HandoffRequest	nas	07 303	D-side
00:22:26.000	CAA4045	MonitorFrequency	datalink	CC 120220	Pilot
00:23:09.000	CAA4045	MonitorFrequency	datalink	CC 120180	Pilot
00:24:25.157	CAA4045	QP	nas	QP CAA4045	D-side
00:24:45.821	KLM1128	LeaderChangeRequest	nas	8 303	D-side
00:24:49.613	KLM1128	MacroTearoffButton2	nas	UH:/0: KLM1128	D-side
00:24:54.000	CAA4045	MonitorFrequency	datalink	CC 120220	Pilot
00:25:25.000	KLM1128	MonitorFrequency	datalink	CC 120070	Pilot
00:27:57.676	KLM1128	QP	nas	QP 303	D-side


CAA4045
KLM1128
Sector 08 Boundary
45
44.5
44
43.5
43
42.5
42
41.5
41
40.5
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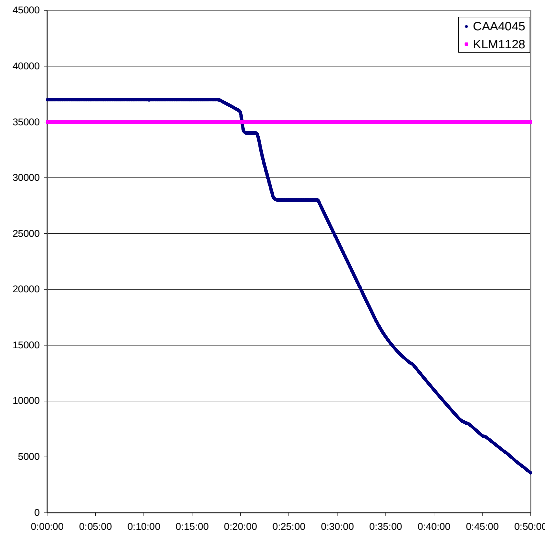
-73.5
-73
-72.5


CAA4045
KLM1128
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40000
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30000
25000
20000
15000
10000
5000
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0:10:00
0:15:00
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